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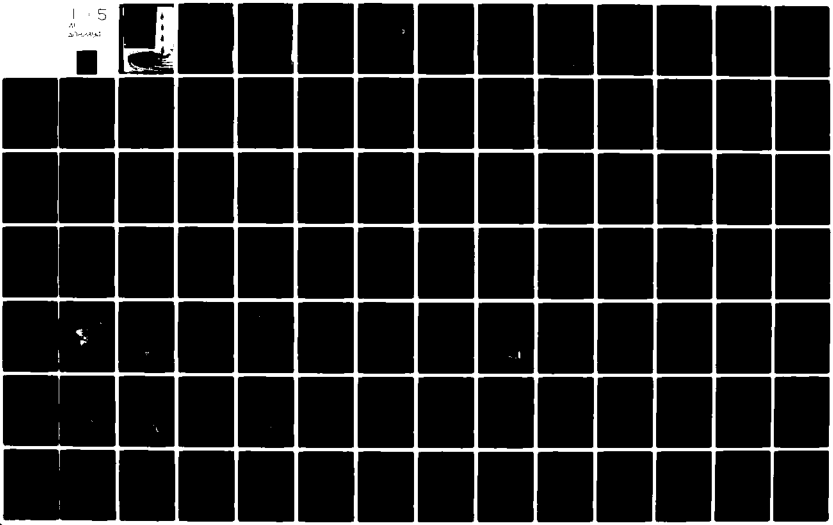

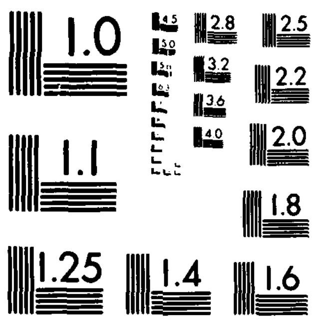

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U.S. ARMY ENGINEER DISTRICT PHILADELPHIA
U.S. ARMY ENGINEER DIV. NORTH ATLANTIC

LEVEL III

DELAWARE RIVER BASIN REPORT

188

DEC. 1960

VOL. IX

APPENDIX P. GROSS AND NET WATER NEEDS

APPENDIX Q. FORMATION OF THE PLAN OF DEVELOPMENT

APPENDIX R. WATER CONTROL AT INTERMEDIATE UPSTREAM LEVELS

APPENDIX S. SALT WATER BARRIER

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This report is Vol. 9 of a comprehensive survey of the water resources of the Delaware River Basin undertaken in the 1950's by the U.S. Army Corps of Engineers. Philadelphia District. Appendix P is an investigation of water use projections for domestic, municipal and industrial water needs plus a study of surface water deficienties in the Lehigh, Upper Schuylkill, Trenton-Philadelphia, Wilmington and Northern New Jersey areas.

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cont.

Formation of plan development is reported in Appendix Q. Water control problems, economic development, dimensions of the flood problem, hydroelectric power markets and both basic and alternative measures to augment supplies of useable water are given.

Appendix R focuses on cost estimates for flood control measures. Studies described in Appendix S show that it would be feasible from an engineering standpoint to construct, operate and maintain a salt water barrier across the Delaware River near New Castle, Del. to halt the intrusion of salt water and create a large fresh water lake which would provide a suitable source of water supply for Northern Delaware.

(1)

REPORT ON THE COMPREHENSIVE SURVEY OF THE WATER RESOURCES OF THE DELAWARE RIVER BASIN

APPENDIX P

GROSS AND NET WATER NEEDS

PREPARED BY

U. S. ARMY ENGINEER DISTRICT, PHILADELPHIA
CORPS OF ENGINEERS
PHILADELPHIA, PA.

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CONTENTS [illegible]

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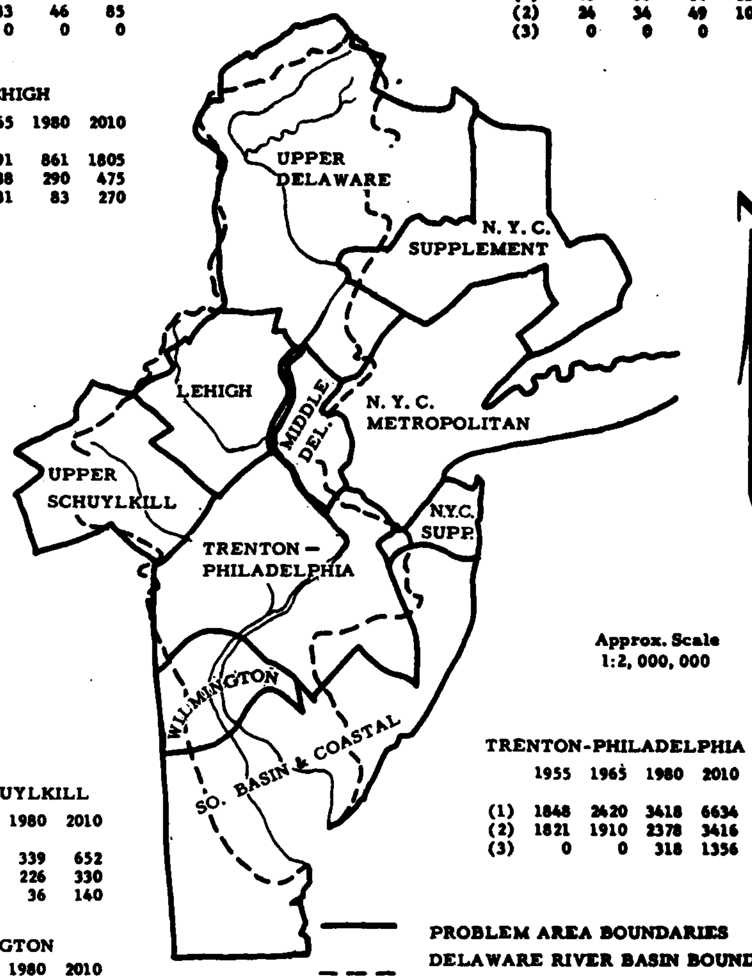
SYLLABUS

The current water needs of the Delaware River basin for all domestic, municipal, industrial and agricultural uses, exclusive of water required for thermal-power cooling purposes, are three billion gallons per day. Of this amount, about 64 percent is found in the Trenton-Philadelphia area, 15 percent in the Bethlehem-Allentown area, 6 percent in the Reading area, 10 percent in the Wilmington area and 5 percent in the Upper Basin and New Jersey. These needs represent all raw water withdrawals being made from Delaware River basin streams, wells, and springs. Of these gross water needs, about 15 percent are supplied from ground water sources and about 85 percent from surface sources. Current levels of surface water withdrawals are such that sufficient streamflow is available to satisfy needs in all areas at present. The growth of water use in this basin is expected to accelerate rapidly during the next fifty years. Commensurate with projected increases in population, industrial and agricultural activity, and standards of living, the gross water needs of this basin are expected to exceed four times the present needs, reaching a daily basinwide requirement of thirteen billion gallons by the year 2010. At that time the gross needs will place a demand of 11.5 billion gallons per day on surface waters. Increased re-use and a planned program for construction of storage reservoirs will permit adequate provision of the projected water needs of this basin. Current and projected gross and net water needs are summarized on the accompanying map.

SYLLABUS APPENDIX P



UPPER DELAWARE

	1955	1965	1980	2010
(1)	40	54	74	128
(2)	21	33	46	85
(3)	0	0	0	0

MIDDLE DELAWARE

	1955	1965	1980	2010
(1)	43	58	80	156
(2)	24	34	49	106
(3)	0	0	0	0

LEHIGH

	1955	1965	1980	2010
(1)	430	591	861	1805
(2)	206	238	290	475
(3)	0	31	83	270

TRENTON-PHILADELPHIA

	1955	1965	1980	2010
(1)	1848	2420	3418	6634
(2)	1821	1910	2378	3416
(3)	0	0	318	1356

UPPER SCHUYLKILL

	1955	1965	1980	2010
(1)	168	238	339	652
(2)	121	176	226	330
(3)	0	0	36	140

WILMINGTON

	1955	1965	1980	2010
(1)	271	1085	1771	3113
(2)	240	993	1636	2910
(3)	0	0	25	340

SO. BASIN & COASTAL

	1955	1965	1980	2010
(1)	86	165	257	494
(2)	13	20	26	42
(3)	0	0	0	0

LEGEND:

(1) GROSS WATER NEEDS
(2) NET SURFACE NEEDS
(3) REQUIRED FLOW AUGMENTATION

All quantities in million gallons per day.

GROSS AND NET WATER NEEDS IN PROBLEM AREAS OF THE DELAWARE RIVER BASIN

GROSS AND NET WATER NEEDS

I INTRODUCTION

1. The purpose of this appendix is to present projections of gross withdrawal needs for all demands on the water resources of the Delaware River basin. Since the water resources under consideration here are those within the basin proper, the needs of primary interest are those originating within the basin boundaries. However, because of the quality and quantity of these water resources and their geographic orientation, areas adjacent to the basin to the east and south, also have turned to the basin's water resources to satisfy portions of their water needs. Thus, the water demands for the New York City Metropolitan Area, the northeast and coastal areas of New Jersey and the south and west portions of Delaware are of interest in these investigations.

2. Projections are made primarily to establish estimates of water quantities. Except for their inherent effects on the quantity of water used, such factors as water quality, costs, and distribution are beyond the scope of this projection study. This appendix presents projections of gross water needs for each of eight economic subregions and reduces gross needs to net water needs in problem areas. The latter are translated into needs for surface stream flow at key stream gaging stations and schedules of surface flow augmentation requirements are presented for each station.

3. In keeping with the place occupied by the water use projections in the overall survey study of the water resources of the basin it was recognized that the projections would need to have breadth not only with regard to area but also with regard to the needs of all inhabitants and all activities within that area. This requirement dictated a broad areal coverage of water needs which would apply consistently throughout the area being studied. It must be recognized therefore that the broad regional projections of water needs required in comprehensive planning for the water resources of the basin differ markedly from the type of projections usually prepared in studies of local needs and distribution problems. In some cases comparisons have been made with local projections furnished by other agencies to demonstrate, insofar as possible, a reasonable level of agreement as to order of magnitude. Such comparisons, however, must not be construed to imply any degree of superiority of one set of results over another. Indeed, the highly speculative nature of any projections would preclude such judgment. A survey of the present scope can only serve as a general guide to the water needs of relatively large economically homogeneous areas and, as a practical measure, must forego the myriad of specific local needs and distribution problems. This appendix projects gross

water needs for the eight economic subregions of the water service area as defined in Appendix B and reduces these needs to specific requirements for surface flow at key places and times during the course of the projection period. These projections are unique and final with respect to the present investigation and serve in part as the basis for subsequent planning related to exploitation of the water resources of the Delaware River basin for a multiplicity of uses. The interdependence of needs for supplies of water with other needs in multiple-purpose projects is discussed in Appendix Q.

4. Gross water needs constitute the sum total of all water required for the domestic, industrial, and agricultural activities of the basin: the total water market. This market and methods of projecting it are described first. Those portions of the gross water market which can be supplied from ground-water sources, saline sources, and by repetitive use of fresh surface sources are discounted to define the net water needs to be supplied from streamflow: the net water market. This market is then examined with respect to available minimum flows to determine where, when, and how much additional surface flow will be required. A system of water supply storage reservoirs is indicated to provide the flow augmentation requirements in sufficient quantity at times and places as needed.

II PROJECTIONS OF GROSS WATER NEEDS

5. General Approach. The projection of gross water needs involves the relation of present and past water use to local and national indices of economic growth. Increased water use is associated with population increases, higher standards of living, technological advances, and industrial and agricultural expansion. Methods of water use projection, therefore, are concerned with the associative relations and interactions of measurable economic growth parameters whose magnitudes may be used as indicators of water use quantities. To explore a variety of approaches, a review of literature was made first and then procedures were devised for application in the Delaware River basin to make the best use of all available pertinent information.

6. Existing Methods. The literature reviewed consisted of papers published in periodicals such as the Journal of the American Water Works Association, Public Works Magazine, Transactions of the American Society of Civil Engineers, reports of several river basin survey commissions and interagency committees, state water resources boards, universities, engineering firms, bulletins of the Departments of the Army, Commerce and Interior. In California 1/ where 90% of the water is used for irrigation, the land utilization method was found effective. In Texas 2/ a detailed breakdown of employment in basic and dependent industries was the principal feature of industrial water projections with attention to changes in productivity per man-hour and efficiency of water use. In Baltimore 3/ per capita increase in consumption of domestic water was put at 2% per year from 1955 to 1975. The Paley Commission 4/ reported an expected industrial water increase of 90% for the nation from 1955 to 1975. Studies in Illinois 5/ demonstrated a relation between family income and residential water use.

1/ California Water Resources Board, Water Utilization and Requirements of California, Bulletin 2, Vol. 1, 1955.

2/ Bureau of Business Research, University of Texas, Water for the Future, Volume Four "Water Requirements in the Texas Gulf Basin", prepared for Bureau of Reclamation, United States Department of the Interior.

3/ John O. Geyer and J. B. Wolff, Report to the Bureau of Water Supply, City of Baltimore, on the Water Distribution System and Appurtenant Problems, Baltimore, Maryland, July, 1955

4/ The President's Materials Policy Commission, Resources for Freedom, Volume V "Selected Reports to the Commission", U. S. Government Printing Office, Washington, D. C., June 1952.

5/ Bernt O. Larson and H. E. Hudson, Jr., "Residential Water Use and Family Income", Journal of the American Water Works Association, August 1951.

Picton 6/ related water use to population growth by application of trends in per capita consumption rates. The method adopted for use in the Delaware River basin relates changes in water use to the movement of personal income.

7. Time and Area Considerations. Projections of water needs are made to the year 2010 with intermediate estimates for the target years 1965 and 1980. The projection period and intermediate years are consistent with standards of other public and private agencies and are the same as used by Office of Business Economics in Appendix B 7/. For the purpose of projecting gross water demands, the Delaware River water service area was subdivided into areal units after the manner of the economic base survey, namely eight economic subregions designated A-H and indicated on plate 1. This subregion arrangement was adopted for gross water demand projections to permit the exploration and application of economic parameters projections of which were made by the Office of Business Economics for these areas. Subsequently the regional projections of water demands were redistributed to hydrologic problem areas (plate 2) which are closely related to the source streams from whose flows the surface water demands are to be met.

8. Definitions of Water Use Categories. For projection purposes water use is divided into two major categories, namely, withdrawal and non-withdrawal uses. Withdrawal uses are classed as domestic-municipal, self-supplied industrial, irrigation and livestock, and other rural uses and include brackish supplies. Non-withdrawal uses include navigation, recreation, pollution and salinity control, and conservation of fish and game. Specific projections for non-withdrawal uses are not made here. However, the effects of stream regulation on these uses will be given consideration in the evaluation of the final plan of development. There are presented, herein, a description of projection procedures and estimates of quantities of water required at future target dates for domestic, municipal and self-supplied industrial withdrawal uses only.

9. Domestic and municipal use comprises all water use for domestic household purposes such as drinking, bathing, cooking, dishwashing, laundry, sanitation, cleaning, lawn sprinkling, gardening, car washing, swimming pools and air conditioning. The domestic element of this category includes water supplied from both municipal

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6/ Walter L. Picton, Water Use in the United States 1900-1975, Business Service Bulletin 136, Business and Defense Series Administration, U. S. Department of Commerce, January 1956.

7/ Appendix B, "Economic Base Survey", prepared by the Office of Business Economics, U. S. Department of Commerce.

and non-municipal sources for the above named household purposes. Also included in the domestic-municipal category are all uses for commercial establishments whose water is supplied from municipal systems such as hotels, restaurants, commercial laundries, office buildings, public garages, and all public uses such as firefighting and street cleaning, and all municipally supplied industries.

10. The self-supplied industrial use category comprises water needs for all industrial uses privately supplied by pumping from wells or streams. For purposes of the present study cooling water for thermal power generation is excluded from this category. Because of the uncertainty of location of thermal power plants with respect to areas of demand, estimates of water needed for this use are indicated only for the water service area as a whole.

11. Basic Data. The detailed analysis of current water use constitutes the base of water projections. The most complete available data on current water use is that for 1955, compiled by the U. S. Public Health Service, as contained in Appendix C 8/. Supplementary 1955 water use data with specific reference to irrigation, livestock, and other rural needs was compiled and furnished by the U. S. Department of Agriculture, contained in Appendix G 9/. The detailed 1955 water consumption also forms the basis for proportioning projected demands among the various economic subregions and among the various categories of use in the future.

12. Related Projections. Independent projections were furnished by other agencies for specific areas. The Commonwealth of Pennsylvania, the States of New York, New Jersey and Delaware and the City of New York provided projections of domestic-municipal water demands in their respective portions of the service area. The State of Delaware also furnished projections for industrial and irrigation water uses 10/. Separate projections of municipal-domestic water demands for New York City and Philadelphia are contained in Appendix C.

8/ Appendix C, "Water Use and Stream Quality", prepared by the U. S. Public Health Service, U. S. Department of Health, Education & Welfare.

9/ Appendix G, "Water for Irrigation and Rural Use", prepared by the U. S. Department of Agriculture.

10/ Appendix O, "Intrastate Water Resources Survey, State of Delaware", prepared by the State of Delaware.

13. Nature of the Problems Attending Gross Water Use Projections. The problem of projecting water demands was fundamentally a two-stage problem. In the first stage, past water use had to be correlated with past economic growth to find the best predicator for estimating water use. In the second stage of the problem, relations and procedures established in the first stage were applied to projections of the pertinent economic indices to predict future water demands. The two stages of the problem were closely linked in the exploratory studies in order to weigh the relative rates of future against past economic growth trends and to establish the nature of the predicator relationships for objection projection to future years. An inherent assumption common to the several projection methods discussed in the following paragraphs, is that changes in the cost of water which are directly associated with implementation of the water control program will have little or no effect on the projected water quantities for domestic and municipal use. Reductions in industrial water use to allow for technological advances, internal recirculation, and conservation practices are given consideration. Experience has indicated that the cost of producing raw water supplies is so small on a per gallon basis that it is of little or no significance when considered in relation to the overall cost of water to the ultimate residential or industrial user.

14. Preliminary Studies of Projection Indices. The search for projection parameters was necessarily limited to those elements of economic growth for which projections were readily available or could be reliably deduced from other available information. The available historical data and projections of the Economic Base Survey consisted of information on population, gross national product, personal income, employment, and households. Each of these economic elements was studied for correlation with past water use separately for domestic and municipal needs and for industrial requirements. The most notable of a variety of alternative indices to emerge from these studies were population, personal income, and parameters associated with land utilization. Methods using these parameters are discussed briefly here to review their salient features and are followed by a complete description of the final adopted procedures which involve a combination of population and personal income.

15. Projection Methods Based on Population. Population has been used traditionally as a basis for estimating future municipal water needs. Where population-water use relationships for a municipality are based on proven empirical relations and the time parameters are kept to reasonably short periods, this method has been found to give fairly dependable projections. Some prior projections have been based on gross population and some, for more limited areas, on the estimated population to be supplied in municipal water service areas. In either case, the estimated population projections

are multiplied by the per capita consumption estimated to be applicable at times in the future. Variations of this method have been used wherein water use values have been applied to estimated population based on assumed saturation for portions of areas under consideration or to the estimated number of households considered likely at times in the future. For industrial water needs projections, employment levels have also been considered along with population. These employment levels are related not only to the population projections but also to the economic condition (at time of projection) of the area under consideration. Thus they tend to provide a general index of industrial water needs of the area. Several variations of employment levels for projecting industrial water requirements have been used by others. Probably the most elaborate of these variations relates unit of water per unit of product or per employee with projections based on future product requirements. In any 50-year projections of domestic, municipal and industrial water needs based on population and employment projections, there are involved also 50-year projections of water-use values per unit of population, employee, or product. These latter projections, when based on local trends, may be found to be adequate for short term projections, but, as in the case of other types of projections involved in this study, their dependability may be expected to vary with the nature and extent of the area and the time parameters used.

16. Projection Methods Based on Land Utilization. Because of differences in the density of population and intensity of land use in portions of the water service area, consideration was given to the land utilization method for projecting gross water requirements. This method, as used in two notable recent surveys (Baltimore and California mentioned in paragraph 6), attempts to forecast ultimate water requirements based on a projected pattern of the ultimate development of land use in various classes combined with estimates of unit water requirements for each class of use. To determine the ultimate requirements for agricultural use, a procedure involving land use patterns and areal values of water use is employed. The genesis of this method was the need to project agricultural water requirements. However, in the determination of probable ultimate requirements for metropolitan areas, most akin to the subregions of the service area, a variation of the land use method known as "population saturation" may be employed. Probable ultimate population estimated on an area-saturation basis is combined with estimates of ultimate per capita water use to determine the ultimate metropolitan water requirement. This can be achieved through a careful land classification survey as well as a projection of the ultimate population of each metropolitan area. Coupled with a study of the ultimate per capita delivery of water for the several classes of urban water use in a metropolitan area it may be possible to derive a gross ultimate water requirement picture. The most salient

feature of this method is the circumvention of the time parameter. Since the water requirements are determined in the ultimate sense there is no pressing need in the forecating step to set a specific year when the ultimate condition may be expected. In one survey, most like the above described method, where a cut-off year was designated, the projection was made not so much to determine if additional water would be required, but how the present distribution system should be strengthened to meet future needs. This is not at all akin to the problem of planning for the optimum development of water resources for the Delaware River. Also, the evasion of the time factor seems to hinder the planner in the sense that there is no way to determine the phasing of necessary projects, save what will be needed for the ultimate. While the land utilization method definitely has the advantage of giving detailed consideration to specific local needs in smaller areal units than the subregions or problem areas of this study, it is emphasized that the present availability of information on water use in relation to land utilization is far from adequate for effective application of this method throughout the basin. The extent and cost of a land utilization survey precludes compilation of additional data within the time limitations and fiscal budget allocated to the present investigation. It is pointed out, however, that projections made by local agencies for specific areas by variants of the land utilization method have been collated with the water demand projections of this appendix and are adequately provided for. Substantiation of the adopted method is given in the following paragraphs.

17. Adopted Method Based on Standard of Living. In the Economic Base Survey it was suggested that personal income in constant dollars would constitute a broad measure of economic growth that might serve as an index to water needs. From detailed investigations, relationships were established between personal income and municipal and industrial water use and methods were established for the direct use of these relations with some modifications to project future domestic-municipal and industrial water needs for the subregions of the water service area. The procedures used in this method will be explained in some detail later in this paper. The standard of living method is based primarily on per capita water use and income data for past years of record and on projections of population and personal income as presented in Appendix B. This method avoids the use of subjective projections of unit water values for each subregion. This is advantageous since all projections for the subregions are susceptible to a degree of error by virtue of the small areas involved.

18. The standard of living method was adopted for both domestic-municipal water and for industrial water projections by relation of water use rates to personal income on the basis of

national trends. For domestic and municipal use projected per capita rates were applied to population projections. For industrial use, portions of personal income derived from key water-using industries were projected and applied to projected ratios of total industrial water use per unit of income in the key industries.

III PROJECTION OF GROSS DOMESTIC & MUNICIPAL WATER NEEDS

19. General application of Standard of Living Method. The adopted method for projecting domestic and municipal water demands involved projection of per capita water use rates by relation to per capita personal income projections. * Population and personal income projections were furnished by the Office of Business Economics. The trend of per capita water use in relation to personal income was established on a national scale and applied to local subregions.

20. Per Capita Water Use and Personal Income. Plate 3 is a semi-log plot of per capita water use versus personal income for the United States from 1930 to 1955. The paucity of historical water use data precludes the firm definition of curve shape. However, a straight line was adopted for extrapolation purposes, since it provided for a decline in the rate of increase of per capita consumption with increasing personal income, recognizing a gradual approach to some upper limit of per capita consumption regardless of income. The national trend of per capita water use versus personal income as defined in plate 3 then, is the basis for projections of per capita water use in the subregions of the Delaware River water service area. Since the relationship is free from the time parameter, it allows per capita water use growth rates in specific local areas to differ from one another and from the overall national growth. The actual time variation of per capita water use is thus made elastic depending on the individual behavior of personal income with respect to time in each specific area.

21. The primary assumption in the case of the national trend is that the standard modes or customs of living reflected by the movement of personal income is a uniform indicator of per capita water consumption. Due to external forces such as degree of urbanization, extent of development of available supplies, capacities and extent of development of distribution systems and other variable factors, a particular custom of living need not reflect the same per capita water use in different local areas. It is expected, however, that the present variations in living customs and water use among local areas and the nation as a whole will continue to maintain a fixed relation to each other. The implication of this assumption is that local communities will continue to grow by expansion of

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* The term "personal income" as used in connection with domestic and municipal water demands hereafter will be understood to mean per capita personal income.

their economy along lines consistent with their present internal economic structure with little change in the present balance of national and regional activities. Economists recognize that radical changes in growth and development are rare. Because the natural course of events is a process of continuous slow evolutionary change, the assumption of a continued fixed relation between the national and local standards or customs of living is reasonable with respect to the time period over which the projections are made. The national trend of per capita water use versus personal income was therefore accepted as applicable to local areas. This principal is best illustrated by reference to data for a subregion of the Delaware River water service area.

22. In subregion "E", for example, the 1955 base water use was 134 gallons per capita per day (GPCD) and the corresponding subregional personal income was $2,240. From the curve of plate 3, the national income at 134 GPCD is $1,875 or 83.7% of that in subregion "E". On the theory that this index of living standards or customs relating the subregion to the living standards or customs of the nation will remain constant throughout the projection period, per capita water use is projected on the national trend by reducing the projected personal income for any local area to the national equivalent in the manner shown for subregion "E" in the following table:

TABLE P-1

REGIONAL & NATIONAL INCOME FOR CORRESPONDING WATER USE

Year	Per Capita Personal Income		Per Capita Water Use Subregion "E"
	Subregion "E" (1)	National Equivalent (2)	GPCD (3)
1955	2,240	1,875	134
1965	2,500	2,090	143
1980	3,100	2,595	161
2010	5,000	4,185	200

The equivalent national income, $1,875, corresponding to the 1955 base water use was read from place 3. The remaining figures in column (2) were computed by multiplying the projected personal income of column (1) by the ratio of the 1955 incomes (living standards index); $\frac{1875}{2240}$ or 0.837. The projected per capita water use,

column (3), was then read from the curve of plate 3 with the equivalent national personal income in column (2). Base national/regional personal income ratios for the eight subregions of the Delaware River water service area are given in table P-2. The magnitudes of these ratios (below 1.0) indicate a lower overall personal income for the nation than income levels prevailing in the Delaware River water service area for the same water use. The application of this method permits use of personal income ratios only at constant 1955 per capita water use levels.

TABLE P-2

NATIONAL AND SUBREGION PERSONAL INCOME FOR 1955
PER CAPITA WATER USE

Sub-Region	Per Capita Water Use GPCD	Per Capita Personal Income: Subregion $PC	Equivalent National for Equal Per Capita Water Use: $PC	Index *
A	131.	2,590	1,800	.695
B	119.3	2,190	1,560	.712
C	131.	2,030	1,800	.886
D	131.5	2,410	1,820	.755
E	134.	2,240	1,875	.837
F	137.	2,970	1,950	.656
G	97.	1,529	1,190	.790
H	96.1	1,735	1,180	.680

* Index = ratio of 1955 incomes (living standards index)

It is emphasized that the term "Equivalent National per Capita Income" applies only to the national income associated with a particular level of per capita water use and application of the ratios in the last column of table P-2 is intended to establish this national equivalent at target years. Therefore any comparison of national income so obtained with actual projected national income for target years should be avoided. The projection of per capita water use rates was accomplished by the application of this procedure in each of the subregions of the water service area. The projected per capita rates are shown on line (12), table P-3. Subsequent multiplication of the projected per capita ratio by populations on line (4), table P-3, gave the water use projections shown on line (8). These projections represent the estimated future domestic and municipal water needs with regard to neither source of supply nor separation of municipal from private sources of supply for domestic use. The analysis of these projections by source categories is described in detail in the following paragraphs.

TABLE P-3. REGIONAL PROJECTIONS OF GROSS WATER NEEDS FOR DOMESTIC & MUNICIPAL USE

	1955	1965	1980	2010	1955	1965	1980	2010	1955	1965	1980	2010	1955	1965	1980	2010
	SUB REGION A				SUB REGION B				SUB REGION C				SUB REGION D			
POPULATION (1000)																
1. Municipal Served from Surface	11103.0	13000.0	15480.0	22250.0	707.7	903.0	1270.0	2377.0	394.2	457.0	581.0	876.0	168.0	207.0	294.0	511.0
2. Municipal Served from Ground	2748.0	3000.0	3020.0	2750.0	195.7	229.0	285.0	405.0	197.3	220.0	261.0	347.0	34.3	39.0	46.0	61.0
3. Other					317.6	368.0	445.0	618.0	206.5	223.0	258.0	327.0	47.7	54.0	60.0	78.0
4. Total	13851.0	16000.0	18500.0	25000.0	1221.0	1500.0	2000.0	3400.0	798.0	900.0	1100.0	1550.0	250.0	300.0	400.0	650.0
WATER USE (MGD) MILLION GALLONS PER DAY																
5. Municipal Served from Surface	1604.3	1987.0	2580.0	4389.0	97.0	142.3	220.5	499.0	57.8	73.2	103.0	190.5	26.1	34.6	53.6	113.7
6. Municipal Served from Ground	214.6	261.0	306.0	434.0	20.2	28.0	39.2	70.7	26.0	32.0	42.5	70.5	3.0	3.8	5.4	9.5
7. Other					28.6	39.7	55.3	100.1	20.6	25.3	33.8	56.0	3.8	4.8	6.8	12.0
8. Total	1818.9	2248.0	2886.0	4823.0	145.8	210.0	315.0	669.8	104.4	130.5	179.3	317.0	32.9	43.2	65.8	135.2
PER CAPITA USE (GPCD) GALLONS PER CAPITA PER DAY																
9. Municipal Served from Surface	144.0	153.0	167.0	197.0	137.0	157.5	173.5	210.0	147.0	160.0	177.5	217.0	155.0	167.0	182.0	223.0
10. Municipal Served from Ground	78.0	87.0	101.0	158.0	103.0	122.0	137.5	174.5	132.0	145.5	163.0	203.0	87.0	98.0	117.0	155.5
11. Other					90.0	108.0	124.0	162.0	100.0	113.4	131.0	171.0	80.0	89.0	113.0	154.0
12. Total	131.0	140.5	156.0	193.0	119.3	140.0	157.5	197.0	131.0	145.0	163.0	204.5	131.5	144.0	164.5	208.0
PROPORTIONS OF GROUND & SURFACE WATER																
13. Surface %	88.2	88.7	89.4	91.0	66.5	67.8	70.0	74.5	55.3	56.1	57.5	60.1	79.3	80.1	81.5	84.2
14. Ground %	11.8	11.3	10.6	9.0	33.5	32.2	30.0	25.5	44.8	43.9	42.5	39.9	20.7	19.9	18.5	15.8
15. PER CAPITA PERSONAL INCOME (1957 Dollars)	2591	2900	3500	5500	2192	2500	3100	5000	2032	2400	3000	5000	2411	2800	3600	6100
	SUB REGION E				SUB REGION F				SUB REGION G				SUB REGION H			
POPULATION (1000)																
1. Municipal Served from Surface	3043.9	3635.0	4532.0	6522.0	183.2	262.0	365.0	656.0	298.0	408.0	490.0	657.0	44.1	54.0	68.0	70.0
2. Municipal Served from Ground	636.5	695.0	772.0	857.0	83.7	110.0	138.0	204.0	106.0	104.0	114.0	132.0	245.2	319.0	461.0	737.0
3. Other	440.6	470.0	496.0	521.0	62.1	78.0	97.0	140.0	147.0	138.0	146.0	161.0	179.7	227.0	321.0	493.0
4. Total	4121.0	4800.0	5800.0	7900.0	329.0	450.0	600.0	1000.0	551.0	650.0	750.0	950.0	469.0	600.0	850.0	1300.0
WATER USE (MGD) MILLION GALLONS PER DAY																
5. Municipal Served from Surface	448.9	563.0	777.0	1358.0	33.3	50.2	75.0	157.2	36.6	52.9	72.6	129.0	6.4	8.7	12.5	16.1
6. Municipal Served from Ground	69.8	82.0	104.2	147.5	7.2	10.8	15.5	30.4	8.0	8.8	11.8	20.0	24.3	36.7	63.7	136.0
7. Other	35.2	41.4	52.6	74.5	4.6	6.7	10.0	19.4	8.8	9.8	13.1	22.0	14.4	21.8	37.8	80.9
8. Total	553.9	686.4	933.8	1580.0	45.1	67.7	100.5	207.0	53.4	71.5	97.5	171.0	45.1	67.2	114.0	233.0
PER CAPITA USE (GPCD) GALLONS PER CAPITA PER DAY																
9. Municipal Served from Surface	147.0	155.0	171.0	208.0	182.0	192.0	205.0	240.0	123.0	130.0	148.0	196.0	145.0	161.0	184.0	230.0
10. Municipal Served from Ground	110.0	118.0	135.0	172.0	86.0	98.0	112.0	149.0	75.0	84.6	104.0	152.0	99.0	115.0	138.0	185.0
11. Other	80.0	88.0	106.0	143.0	75.0	86.0	103.0	138.5	60.0	71.0	89.7	137.0	80.0	96.0	118.0	164.0
12. Total	134.0	143.0	161.0	200.0	137.0	150.5	167.5	207.0	97.0	110.0	130.0	180.0	96.1	112.0	134.0	179.0
PROPORTIONS OF GROUND & SURFACE WATER																
13. Surface %	81.1	82.0	83.3	85.9	73.8	74.1	74.7	76.0	73.6	74.0	74.5	75.6	14.2	12.9	11.0	6.9
14. Ground %	18.9	18.0	16.7	14.1	26.2	25.9	25.3	24.0	26.4	26.0	25.5	24.4	85.8	87.1	89.0	93.1
15. PER CAPITA PERSONAL INCOME (1957 Dollars)	2241	2500	3100	5000	2972	3500	4300	7000	1529	1800	2300	4200	1735	2100	2700	4700

23. Water Use Projections in Source Categories. By the procedure described in paragraph 22, projections of gross domestic and municipal water use were made within each subregion in three service categories with reference to the source of supply from which the water was served. These categories accounted for domestic and industrial needs served by municipal systems; (a) from surface sources and (b) from ground-water sources; and domestic needs not served by municipal systems. The last is designated "other" category and for purposes of the present study is assumed to be supplied from ground sources. All population figures were corrected for summer residents. By reason of including the "other" category, the subregion totals of population, water use, and per capita use differ from the data published in tables 4, 5, and 6 of the U. S. Public Health Service report (March 1959). Projection of water use by source categories permits recognition of different growth rates among the categories with respect to changing proportions of water served from ground and surface sources. As communities grow and municipal distribution systems extend their service areas it is expected that greater emphasis will be placed on obtaining water from surface sources with a resulting decline in the relative proportion of water served from ground sources. For purposes of the present study, the decline in the proportion of ground water served was put at 2% - 5% per decade in regions A - G but because of the present abundant ground-water resources, the proportion was estimated to increase 1.5% per decade in subregion H. Decennial rates of change in the percent of ground-water use are as follows in the eight subregions: A, -4.0%; B, -4.0%; C, -2.0%; D, -3.0%; E, -5.0%; F, -1%; G, - 1.5%; and H, +1.5%. These estimated changes were applied to the 1955 proportions of ground-water use to obtain the projected proportions of groundwater and surface water shown on lines (13) and (14), table P-3. A further breakdown of the ground-water component into municipally and privately supplied ground water as indicated by the 1955 use data then permitted estimation of the water use quantities for the source categories as shown on lines (5), (6), and (7), table P-3. As a check on this distribution, per capita use in each source category, projected by the procedure described in paragraph 22, was applied to the water use in each category to obtain estimates of population in each source category. These population estimates agreed with the projected total subregion populations within 5%. Minor adjustments then provided the per capita use rates shown on lines (9), (10), and (11) and the populations shown on lines (1), (2), and (3) of table P-3. An acceptable level of consistency is thus demonstrated by the close agreement of source category population totals with the Office of Business Economics' population projections.

24. The primary feature of this technique is its freedom from hunch type forecasts of growth rates. Aside from basic assumptions, the only element of judgment required in the application of the procedure was in the projection of future proportions of ground and surface water. The magnitude changes involved are relatively small, however, and the final projections of water use are not particularly sensitive to the assumed rates of change of ground-water use. The inclusion of prospective changes in ground-water use, however, serves to recognize the likelihood of such changes in the future, thereby adding greater realism to the final result. A complete summary of all pertinent parameters and final projections of domestic and municipal water is shown in table P-3. The projections of gross water needs for domestic and municipal use are shown for the eight subregions on plate 4.

IV PROJECTION OF GROSS INDUSTRIAL WATER NEEDS

25. Adopted Method - Gross Industrial Water Demands. As in the case of the domestic and municipal water demands, the personal income parameter was adopted for industrial water projections. The manner of application of personal income in the case of industrial water use was somewhat different, however. Instead of per capita use, total industrial * use is directly related to personal income. The projection of self-supplied industrial water is essentially a problem of projecting water use in heavy water using industries. Manufacturing industries account for almost all industrial water needs exclusive of water required for thermal power generation. Personal income derived from manufacturing industries, therefore, is an index of gross industrial water use in that it reflects average productivity in these industries which in turn, is directly related to the average water requirements of the various manufacturing processes.

26. General Application of Standard of Living Method. The previous section dealt with the relation of per capita water use to per capita personal income for projecting domestic and municipal water use. This section deals with the projection of gross self-supplied industrial water use by its relation to personal income derived from manufacturing industries. In this case, totals rather than per capita values of water use and income are employed. Civilian earnings in manufacturing industries are employed here because manufacturing industries account for nearly all industrial water needs exclusive of cooling water for thermal power generation. Water needs for thermal power cooling purposes are projected separately. Civilian earnings in manufacturing industries reflect the heavy water using requirements of the various manufacturing processes by their relation to average productivity. Civilian earnings in manufacturing consist of wages, salaries, other labor income, and proprietor's income.

27. In 1955 total personal income and civilian earnings in manufacturing in the United States were 318 billion dollars and 80 billion dollars respectively. Self-supplied industrial water use (as given by Picton) was 60 billion gallons per day (GPD). These data indicate that manufacturing earnings constituted about 25% of the total national personal income and that industrial

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* As used hereafter in the present context it will be understood that industrial water refers to all self-supplied industrial water exclusive of thermal power generation needs. Industrial water needs supplied from municipal systems are included in projections of domestic and municipal water use.

water was used at the daily rate of 0.75 gallons per dollar of manufacturing earnings. Historical data also show that manufacturing earnings have tended to grow faster than total personal income but that the rate of water use per unit of manufacturing earnings has tended to decline. For projection purposes, then, a relationship was first derived to relate manufacturing earnings to total personal income which would recognize this tendancy for manufacturing earnings to represent a higher share of total personal income in the future. The relation of self-supplied industrial water use to manufacturing income, on the other hand, had to recognize a decreasing rate of industrial water use per dollar of manufacturing income as time goes on. The derivation and application of these two basic relations provided the projection procedure and the projected magnitudes of gross water needs for self-supplied industrial water use.

28. Civilian Earnings in Manufacturing Industries. A plot of national manufacturing earnings versus total personal income for the period 1929-1956 exhibited a linear trend as shown on figure 1, plate 5. The relationship indicates the manufacturing earnings will eventually approach thirty percent of the national total personal income, as can be seen in figure 2 plate 5. Extrapolation of the national trend of figure 1, permitted estimation of manufacturing earnings at target years by application of projections of total personal income for the United States furnished by the Office of Business Economics. For this projection it was assumed on the basis of persistence that the historical linear trend would continue over the projection period. The implication of linearity in the extrapolation is that future national manufacturing earnings will assume a progressively larger proportion of total personal income but that this proportion will eventually approach an upper limit. The growth of the proportion of total income accounted for in manufacturing earnings is shown in the following table for 1955 and for the target years:

TABLE P-4

COMPUTATION OF PROJECTED SHARES OF MANUFACTURING EARNINGS FROM TOTAL PERSONAL INCOME IN THE UNITED STATES

Year	Total Personal Income Billion Dollars	Civilian Earnings in Manufacturing Billion Dollars	Share of Manufacturing Earnings Ratio	Share of Manufacturing Earnings % of 1955
(1)	(2)	(3)	(4)	(5)
1955	318.4	80.7	0.253	100
1965	450	120	0.267	105
1980	725	203	0.280	110
2010	1,800	527	0.293	116

Column (2) in the above table shows the projected total personal income. Column (3) shows the projected civilian earnings in manufacturing as estimated from column (2) and the relation of figure 1, plate 5. The share of manufacturing earnings is the ratio of column (3) to column (2) as shown in column (4). Finally column (5) shows the percentage growth of the ratio with respect to the 1955 base. Thus, the share of total personal income to be derived from manufacturing industries is expected to be 5% higher in 1965, 10% higher in 1980, and 16% higher in 2010. This indicated growth reflects a tendency for manufacturing income to assume a moderately higher share of total personal income as time goes on. By use of this national growth trend the 1955 subregion ratios of manufacturing civilian earnings to total personal income were projected forward to the target years and applied to the Office of Business Economics projections of total personal income in the subregions to obtain projected manufacturing income as shown on lines 1, 2, and 3 in table P-5. The general implication of this projection is that the growth of income derived from manufacturing industries will bear the same relation to growth of total personal income in the subregions as at the national level. While some data were available to relate manufacturing income to total personal income on a regional basis, detailed studies indicated that greater confidence could be placed in the regional projections based on the national trend. Projection of manufacturing earnings by the national trend recognized growth variations among the subregions as shown in figure 3, plate 5, because of differences in the 1955 base ratio and because of differences in total income growth rates as projected by the Office of Business Economics. Subregion E exhibits a growth similar to that for the entire basin. Manufacturing earnings grow faster in subregions C, D and F and not as fast in subregions G and H. The variations of subregion manufacturing income with time is shown in figure 4, plate 5. Adjustments for unusual departure from the average due to location of a particularly heavy water using industry will have to be made in each area as income and water use projections are revised during the course of the projection period. Such a case occurred during the period of this investigation with installation of an oil refinery by the Tidewater Oil Company in the Wilmington area. Projections for that area have been revised upward accordingly.

29. Industrial Water Use in Relation to Manufacturing Personal Income. The estimation of future earnings in manufacturing industries, has been accomplished by the method described in the preceding paragraphs. It now remains to estimate projected self-supplied industrial water use by application of appropriate ratios of water use per unit of manufacturing earnings to the income projections so obtained. The following paragraphs discuss the projection of these ratios. In this connection it must be remembered

that the ratios relate total self-supplied water use for all industries to civilian earnings in manufacturing industries only.

30. Picton 11/ related national self-supplied industrial water use to the index of industrial production. Since the latter index is highly correlated with gross national product (GNP), it was possible to project Picton's data to 2010 with Office of Business Economics' projection of GNP by means of a straight line semi-log relation. The relation expressed historical self-supplied industrial water use for the nation as a function of log (GNP + 700) with GNP in billions of 1957 dollars. The future variation of national industrial water use with time as obtained from this relation is shown as curve (1), figure 1, plate 6, with reference to the right hand scale of the figure. On the basis of this projection, a second relation was developed associating self-supplied industrial water use with civilian earnings in manufacturing industries. The second relation was designed to permit application of an independent variable for which regional projections could be obtained. From this second relation, ratios of industrial water use to manufacturing earnings were computed and plotted as curve (1), figure (1), plate 6, with reference to the left hand scale. These ratios represent the daily rate of total self-supplied industrial water use per dollar of manufacturing earnings (GPD/$), and decrease by approximately 35% over the projection period changing from about 0.75 GPD/$ in 1955 to 0.50 GPD/$ in 2010. Alternately, curves (2) represent an extreme condition in which the GPD/$ rate is held constant over the projection period. While such a situation is not likely to occur, these curves show that no decline in the GPD/$ rate would result in a national 2010 industrial water requirement nearly double that indicated by tentative estimates from curves (1). As another alternate, the equally unlikely opposite extreme, that of holding industrial water use constant over the projection period, would result in a drastic drop of about 85% in the GPD/$ rate as shown by curves (3) in figure 1, plate 6. From the curves of figure 1, plate 6, it may be seen that the tentative estimates from curves (1) puts industrial water use in 2010 about midway between the two extremes discussed above. In the interests of conservatism, however, the adopted decline in the GPD/$ rate was chosen so as to make the drop 25% over the projection period. With a uniform rate of decline, the 1965, 1980 and 2010 percentages are respectively 95.5, 88.7, and 75.0 percent of the 1955 GPD/$ rate. These

11/ Picton, Walter L., Water Use in the United States, 1900-1975, Business Services Bulletin #136, January 1956, Water and Sewerage Industry and Utilities Division, Business and Defense Services Administration, U. S. Department of Commerce.

TABLE P-5

REGIONAL PROJECTIONS OF GROSS WATER NEEDS FOR SELF-SUPPLIED INDUSTRIAL USE

	1955	1965	1980	2010	1955	1965	1980	2010	1955	1965	1980	2010
	SUB REGION C				SUB REGION D				SUB REGION E			
PERSONAL INCOME 1/												
1. Total	1,620	2,200	3,300	7,800	600	900	1,400	4,000	9,230	12,100	17,800	39,500
2. Mfg Earnings as % of Total Personal Income	41	43	45	48	33	35	36	39	30	32	33	35
3. Manufacturing Civilian Earnings 2/	670	950	1,480	3,740	200	320	500	1,560	2,800	3,870	5,870	13,820
WATER USE (MGD)												
4. Rate GPD/$1000 3/	570	540	510	430	250	240	220	190	430	410	380	320
5. Total Use	380	513	755	1,608	50	77	110	296	1,201	1,587	2,231	4,422
6. Supplied from surface sources	344	468	698	1,521	46	71	102	281	1,111	1,474	2,086	4,188
7. Supplied from ground sources	36	45	57	87	4	6	8	15	90	113	145	234
PROPORTIONS OF SURFACE & GROUND												
8. Surface %	90.5	91.2	92.4	94.6	91.7	92.3	93.2	95.0	92.5	92.9	93.5	94.7
9. Ground %	9.5	8.8	7.6	5.4	8.3	7.7	6.8	5.0	7.5	7.1	6.5	5.3
	SUB REGION F 4/				SUB REGION G				SUB REGION H			
PERSONAL INCOME 1/												
1. Total	980	1,600	2,700	7,000	840	1,200	1,800	4,000	810	1,300	2,300	6,100
2. Mfg Earnings as % of Total Personal Income	39	41	43	46	23	24	25	27	18	19	20	21
3. Manufacturing Civilian Earnings 2/	380	660	1,160	3,220	190	290	450	1,000	150	247	460	1,280
WATER USE (MGD)												
4. Rate GPD/$1000 3/	580	550	510	440	720	690	640	540	220	210	190	160
5. Total Use	222	1,000	1,650	2,885	137	200	288	583	33	52	87	205
6. Supplied from surface sources	206	933	1,549	2,744	114	168	246	516	6	10	15	32
7. Supplied from ground sources	16	67	101	141	23	32	42	67	27	42	72	173
PROPORTIONS OF SURFACE & GROUND												
8. Surface %	92.9	93.3	93.9	95.1	83.1	84.1	85.6	88.6	19.3	18.5	17.3	15.7
9. Ground %	7.1	6.7	6.1	4.9	16.9	15.9	14.4	11.4	80.7	81.5	82.7	84.3

1/ All income figures in millions of 1957 dollars.
2/ Consists of wages, salaries, other labor income, and proprietors' income.
3/ Rate of industrial water use per unit of civilian earnings in manufacturing industries - gallons per day per thousand dollars.
4/ Projections of water use quantities for Sub-region F modified for new Tidewater plant after 1957.

percentages were applied directly to the known 1955 subregion rates to obtain subregion target year values of the GPD/$ rate as indicated in line 4, table P-5. The apparently high rate of industrial water use per dollar of manufacturing income in subregion G reflects the preponderance of the heavy water using mining industries in portions of that area. Multiplication of the GPD/$ rates on line (4) by manufacturing income on line (3) then gave the projections of total gross self-supplied industrial water needs shown on line (5), table P-5.

31. Subregions A and B have been omitted from table P-5 since provision for their needs is beyond the scope of the present investigation. As a matter of comparative interest, however, these subregions' needs were also examined. Projections of gross industrial water needs were made for subregions A and B, following generally the procedures used for the other subregions. In the absence of actual survey data, estimates of current (1955) industrial water use and GPD/$ rates were assigned primarily by judgment in relation to similar values for subregions C thru H. Based on such estimates of current industrial water use, projections of gross industrial use for subregions A and B were deduced simply to fill out the gross water demand picture for the entire water service area as shown below.

ESTIMATED GROSS INDUSTRIAL WATER USE - MGD

Sub-Region	1955	1965	1980	2010
A	2500	3400	4600	8800
B	410	610	970	2370
Total(A + B)	2910	4010	5570	11170

These estimates for the combined subregions are also shown in table 8 for comparisons with gross water needs of other subregions of the service area.

32. In general the validity of the industrial water projections is subject to the assumption that the water use in manufacturing reflects, in a dependable manner, the major portion of industrial water use and further that the growth of industry and its associated water uses is adequately reflected by the movement of the portion of personal income contributed by manufacturing industries. The precision of the projections is subject to the judgment of the economist and planner in estimating future personal income,

in estimating changes in future proportions of manufacturing earnings with respect to total personal income and changes, and in estimating the future unit values of industrial water use per unit of manufacturing earnings. The tendency of personal income in manufacturing to represent a higher future proportion of total personal income, has a counteracting effect on the tendency of industry to use less water per dollar of personal income. The method, by including these effects, however, recognizes the interaction of these forces and is thereby made flexible and sufficiently general for re-evaluation of projections as more information becomes available in the future.

33. Sources of Industrial Water. The procedure just described provides projections of gross self-supplied industrial water within the Delaware River basin without regard to source of supply. For purposes of planning augmentation of surface flow, it is desirable to separate the gross need for industrial water into categories of supply with respect to surface and ground sources. The proportions of water in surface and ground categories are known only for the base year, 1955, and must be estimated for the target years. As in the case of domestic-municipal water projected rates of change in the proportion of ground water were based on estimates of probable future changes in each subregion taking account of the relative degree of industrial development with respect to location in relation to surface and ground sources, and the present (1955) proportions of water in these categories. The assumed decennial changes in percent of ground-water use are as follows: Subregion C, -0.7%; Subregion D, -0.6%; Subregion E, -0.4%; Subregion F, -0.4%; Subregion G, -1.0%; Subregion H, +0.8%. A negative sign indicates a rate of decline; a positive sign a rate of increase. The greatest proportionate decline in ground-water use is expected in Subregion G, the Upper Basin. It should be noted, however, that a decline in the proportion of industrial water supplied from ground sources does not imply a decrease in ground-water use as time goes on. The gross increases of industrial water use in general offset the decline in proportions of ground water such that future industrial ground-water use is actually increasing as may be seen by reference to line 7, table 5, and plate 7, which show the final projections of industrial water use broken down into surface and ground-water categories by subregions.

V WATER USE PROJECTIONS FOR PROBLEM AREAS

34. Definition of Problem Areas. The preceding paragraphs have dealt with methods of arriving at estimates of future gross subregion requirements of water for domestic, municipal, rural, agricultural, and industrial uses. The procedures were described and the estimated gross water needs were presented for 1965, 1980 and 2010 for the subregions of the economic base survey. The ultimate application of this water demand information requires that consideration be given to the particular areas and drainage patterns from which surface water will be available to meet specific local needs. In subregion C, for example, the Bethlehem-Allentown and Reading metropolitan areas, Bethlehem and Allentown are served by the Lehigh River while Reading is served by the Schuylkill River. From the hydrologic viewpoint, therefore, it was necessary to group the counties through which these rivers flow with a view to their need for augmentation of surface flow in relation to demands. Thus, Schuylkill county and Berks county are taken away from subregions G and C respectively and combined to constitute a water problem area designated the Upper Schuylkill area. Refer to maps, plates 1 and 2. Similarly, Lehigh River water is expected to serve Carbon, Lehigh and Northampton counties. These three counties, therefore, constitute the Lehigh River water problem area. The remainder of subregion G, after removal of Schuylkill county to the Upper Schuylkill and Carbon county to the Lehigh area constitutes the Upper Delaware problem area. The counties of Warren and Hunterdon in New Jersey make up the Middle Delaware problem area. Mercer county served by the Delaware River and subregion E served both by the Schuylkill and Delaware Rivers are combined to form the Trenton-Philadelphia problem area. Subregions A, B, F, and H retain their identities as problem areas. Chester county, Pennsylvania, is situated in an area served by the Upper Brandywine. However, this county had been included in subregion E for economic analyses and was retained as part of the Trenton-Philadelphia water problem area. While Chester county is linked hydrologically to the Wilmington area, it was expedient to avoid compounding water supply problems of the Wilmington area by leaving Chester county in subregion E. The primary needs of Chester county will be served by the Commonwealth of Pennsylvania's water resources development plan of Brandywine Creek basin 12/. The Commonwealth's plan includes construction of five multiple-purpose projects which are expected to augment the minimum flow of

12/ Bourquard, Geil & Associates, Report on Water Resources Study of Brandywine Creek Basin in Pennsylvania, Harrisburg, Pa., December 1958 and Supplement, November 1959.

Brandywine Creek at Wilmington as discussed in section on area of indicated water deficiencies. It is assumed that the State of Delaware and the Commonwealth of Pennsylvania will reach a mutually satisfactory operating arrangement with respect to the Brandywine plan. For purposes of the present study, then, the Wilmington problem area consists only of New Castle county. The water problem areas thus defined are depicted on the basin map, plate 2.

35. Domestic and Municipal Water Needs in Problem Areas. The translation of domestic and municipal water needs from subregions to problem areas was accomplished through the medium of the 1955 county populations and water use. From county data and the proportions of population as redistributed among the problem areas in 1955, estimates were made of projected problem area populations in the three source categories and applied to projected per capita water use rates of the parent subregion to obtain surface, ground, and other municipal water use. This redistribution was based on population to make use of available data and is in keeping with the assumption of uniform per capita water use throughout the subregion. A sample computation for the Upper Delaware problem area will serve to illustrate this process. This problem area is made up of the remainder of subregion G after subtracting Schuylkill and Carbon counties. The 1955 population distribution is indicated in the following table:

TABLE P-6

1955 POPULATION DISTRIBUTION - UPPER DELAWARE PROBLEM AREA

Service Category	Subregion G 1955 Population 1000's	Schuylkill and Carbon Counties 1955 Population 1000's	Upper Delaware Problem Area 1000's	Upper Delaware Problem Area % of Subregion
	(1)	(2)	(3)	(4)
Municipal Surface	298	185	113	38.0
Municipal Ground	106	53	53	50.0
Other	147	11	136	92.5

The percentages in column (4) are obtained by dividing the problem area populations in column (3) by the subregion population in column (1). With these percentages, it is possible to translate the projected subregion water requirements as illustrated by the following computation for the year 1980. The 1980 target year subregion populations are shown in column (1) below. Column (2) lists the percentages found from the 1955 population distribution. The subregion populations are then multiplied by the percentages to get the problem area populations in column (3):

TABLE P-7

1980 WATER USE - UPPER DELAWARE PROBLEM AREA

Service Category	1980 Population: Subregion G 1000's (1)	Upper Delaware Problem Area % of Subregion (2)	Upper Delaware Problem Area 1000's (3)	1980 Water Use GPCD (4)	1980 Water Use MGD (5)
Municipal Surface	490	38.0	186	148.0	27.6
Municipal Ground	114	50.0	57	104.0	5.9
Other	146	92.5	135	89.7	12.1
TOTAL					45.6

The per capita water use rates in column (4) are the adjusted rates for the subregion as found in the original domestic-municipal water projections shown under 1980, subregion G, lines 9, 10 and 11, table 3. Lastly, multiplication of the problem area populations in column (3) by the subregion per capita rates in column (4) gives the water use in column (5). Summation of column (5) then gives the total problem area water use. This procedure is carried out in similar fashion for all problem areas and for each of the target years and provides the gross domestic and municipal water demands of the problem areas as shown in table P-8.

36. Industrial Water Needs in Problem Areas. In the case of the industrial water needs, redistribution of the projections from subregions to problem areas was accomplished by direct application of the proportions of 1955 industrial water use among the subregion problem area components. Of the 113 MGD used by industry from surface sources in subregion G, for example, 105 MGD were used in Schuylkill and Carbon counties leaving a remainder of 8 MGD used in the Upper Delaware problem area or 7.1% of the subregion total surface water. Similarly the problem area used 4.3% of the subregion total industrial water supplied from ground sources. These percentages uniformly applied to subregion projections of industrial water in surface and ground categories gave the projections of industrial water in the target years for this problem area. The problem area projections obtained in this way by redistribution of subregion projections of industrial water requirements in ground and surface categories are shown in table P-8.

37. Water Needs for Irrigation, Livestock, and Other Rural Uses. The U. S. Department of Agriculture was assigned the responsibility for projecting the agricultural and rural water needs of the basin. These projections are presented and discussed in detail in Appendix G. The areal subdivision of the Delaware basin used by the U. S. Department of Agriculture consisted of 10 sub-basins as indicated on figure 1, Appendix G. By appropriate groupings of these sub-basins, totals of water use for approximate problem areas were estimated. These are shown in table P-8. As indicated in table P-8, agricultural water needs for the Middle Delaware and Upper Schuylkill areas are included in the Trenton-Philadelphia area. Projections of gross water needs for irrigation, livestock and other rural uses are shown in figure 1, plate 8. Although the irrigation component of these needs is a seasonal demand occuring only during the growing season, the total agricultural demands are relatively so small with respect to the overall water needs for domestic, municipal and self-supplied industrial use that no adjustment has been made for the seasonal effect of the irrigation demand.

TABLE P-8

SUMMARY OF GROSS WATER DEMANDS IN PROBLEM AREAS

(All quantities in million gallons per day)

PROBLEM AREA AND CATEGORY	1955			1965			1980			2010		
	SURFACE	GROUND	TOTAL	SURFACE	GROUND	TOTAL	SURFACE	GROUND	TOTAL	SURFACE	GROUND	TOTAL
UPPER DELAWARE												
Domestic and municipal	14	12	26	20	14	34	28	18	46	40	30	70
Self-supplied industrial	8	1	9	12	1	13	18	2	20	38	3	41
Irrigation, livestock, and rural	2	3	5	3	4	7	4	4	8	4	4	8
Total	24	16	40	35	19	54	50	24	74	[illegible]	37	120
MIDDLE DELAWARE 1/												
Domestic and municipal	4	8	12	6	10	16	8	13	21	15	22	-
Self-supplied industrial	21	10	31	29	13	42	43	16	59	98	24	
Total	25	18	43	35	23	58	51	29	80	120		
LEHIGH												
Domestic and municipal	35	26	61	45	31	76	63	42	105	116	70	[illegible]
Self-supplied industrial	347	20	367	485	26	511	720	32	752	1,[illegible]	40	1,[illegible]
Irrigation, livestock, and rural	1	1	2	3	1	4	3	1	4	3	1	4
Total	383	47	430	533	58	591	786	75	861	1,[illegible]	[illegible]	1,[illegible]
UPPER SCHUYLKILL 1/												
Domestic and municipal	41	17	58	55	21	76	77	28	105	130	46	[illegible]
Self-supplied industrial	82	28	110	123	39	162	184	50	234	[illegible]	81	467
Total	123	45	168	178	60	238	261	78	339	525	127	[illegible]
TRENTON-PHILADELPHIA												
Domestic and municipal	475	112	587	598	132	730	831	169	1,000	1,472	243	1,715
Self-supplied industrial	1,157	94	1,251	1,542	118	1,660	2,225	155	2,380	4,623	258	4,881
Irrigation, livestock, and rural	5	5	10	19	11	30	24	14	38	24	14	38
Total	1,637	211	1,848	2,159	261	2,420	3,080	338	3,418	6,119	515	6,634
WILMINGTON												
Domestic and municipal	33	12	45	50	18	68	75	25	100	157	50	207
Self-supplied industrial	206	16	222	933	67	1,000	1,550	100	1,650	2,744	141	2,885
Irrigation, livestock, and rural	2	2	4	12	5	17	15	6	21	15	6	21
Total	241	30	271	995	90	1,085	1,640	131	1,771	2,916	197	3,113
SOUTHERN BASIN AND COASTAL												
Domestic and municipal	6	39	45	9	58	67	13	101	114	16	217	233
Self-supplied industrial	6	27	33	10	42	52	15	72	87	32	173	205
Irrigation, livestock, and rural 2/	5	3	8	8	38	46	10	46	56	10	46	56
Total	17	69	86	27	138	165	38	219	257	58	436	494
DELAWARE RIVER BASIN												
Domestic and municipal	608	226	834	783	284	1,067	1,095	396	1,491	1,964	678	2,642
Self-supplied industrial	1,827	196	2,023	3,134	306	3,440	4,775	427	5,182	9,484	729	10,213
Irrigation, livestock	15	15	29	45	59	104	56	71	127	56	71	127
Total	2,450	436	2,886	3,962	649	4,611	5,906	894	6,800	11,504	1,478	12,982
NYC METROPOLITAN AND SUPPLEMENT 3/												
Domestic and municipal	1,701	263	1,964	2,129	329	2,458	2,801	400	3,201	4,888	605	5,493
Self-supplied industrial	-	-	2,910	-	-	4,010	-	-	5,570	-	-	11,170
Total	-	-	4,874	-	-	6,468	-	-	8,771	-	-	16,663
DELAWARE RIVER SERVICE AREA												
Domestic and municipal	2,309	489	2,798	2,912	613	3,525	3,896	796	4,692	6,852	1,283	8,135
Self-supplied industrial	-	-	4,933	-	-	7,450	-	-	10,750	-	-	21,383
Irrigation, livestock, and rural 4/	15	14	29	45	59	104	56	71	127	56	71	127
Cooling water for thermal power 5/	3,406	-	3,406	6,115	-	6,115	12,442	-	12,442	37,779	-	37,779
Total	-	-	11,166	-	-	17,194	-	-	28,013	-	-	67,424

1/ Irrigation, livestock, and other rural water use for Middle Delaware and Upper Schuylkill included in Trenton-Philadelphia problem area.
2/ Irrigation, livestock, and other rural water use for Southern Basin only, exclusive of Coastal Area.
3/ Domestic and municipal water use for NYC & SUPPLEMENT (subregions A & B) includes rural residential use in subregion B only and excludes self-supplied industrial water use in both A & B.
4/ Projections of irrigation, livestock and rural use not available for areas outside basin.
5/ Generation estimated for service area only.

VI PROJECTIONS OF WATER NEEDS IN OTHER USE CATEGORIES

38. Rural Residential Water Use. U. S. Department of Agriculture projections of gross water needs for rural residential use are shown separately in the upper portion of figure 2, plate 8, in comparison with projections of water need for non-municipally supplied domestic use made by the method of this appendix. In the lower portion of figure 2, plate 8, per capita use rates of the two methods are compared. The differences between the two are attributable mainly to differences in the extent of the two categories. The rural use given by the U. S. Department of Agriculture embraces only those extreme outlying areas whose principal activity is agriculture. The "other" category of the domestic and municipal projections of this appendix includes all population not accounted for in the municipally served category. Therefore, the population projections of the "other" category behave differently from those of the U. S. Department of Agriculture for their rural residential use category. In general, however, the projections of this appendix adequately provide for the rural use needs indicated by the U. S. Department of Agriculture. For the basin as a whole, agricultural needs represent about 1% of the gross water needs for domestic and industrial purposes. The total basin water requirements for irrigation, livestock, and other rural uses will be about 130 million gallons per day. This quantity represents the average annual need for water in this category. It is pointed out, however, that the irrigation portion of this need put on a 60-day growing season basis would be 688 MGD or about 5% of the total basin requirement for all uses by 2010. Since the larger magnitude associated with the irrigation needs is a seasonal demand, no adjustment has been made for it. Seasonal variations are discussed in paragraph 41. Plate 9 shows the relation of agricultural water use to other uses on a basinwide basis.

39. Thermal-Electric Cooling. The nature of the electric power transmission network provides for the integration of many different thermal-power sources within a single distribution grid serving an area far beyond the limits of the Delaware River basin. For this reason, it is not possible to pinpoint projected thermal-electric cooling water needs in specific areas within the basin. However, on the basis of a uniform rate of use of cooling water for this purpose 608 GPD per kilowatt of continuous power, projections of thermal cooling water were made for the entire Delaware River water service area as shown on the last line of table P-8. The quantities for 1980 and 2010 were reduced to allow for hydroelectric power generated at Tocks Island. In general, the use of thermal cooling water is not expected to impose any additional demand upon the net surface flow requirements for other uses. Since economies in use of

thermal-electric cooling will be realized in the near future due to increased fuel efficiencies, the unit rate of water use for this purpose may be expected to decline. The projected estimates based on a uniform rate may therefore be regarded as conservative. The augmented flows to be provided by the proposed plan of development are considered to be sufficient for thermal-electric power needs.

40. Navigation. Water needs for navigation purposes are discussed in Appendix E 13/. These are, in general, non-withdrawal needs with the notable exception of the cross-Jersey canal for which as much as 710 cfs may be required for diversion from the Delaware River. Such diversion, if made, would constitute a withdrawal of water from the basin's resources. However, the feasibility of the canal and the reality of need for this water has yet to be demonstrated. The present study, therefore, makes no allowance for this purpose. At such time as the need for this canal is positively established, additional compensating storage will have to be studied as possible means of supplying the required fresh water flow.

41. Seasonal Variations. Seasonal variations have been shown by U. S. Public Health Service to be on the order of 10% of the average annual water use in 1955. The nature of the water use projections and the extreme variability of actual consumption from year to year are sufficiently broad to obscure variations of this magnitude. Therefore allowances for seasonal variations as such have been omitted. It is pointed out, however, that with ultimate implementation of the water control plan, such variations may be easily absorbed in the establishment of reservoir operation schedules.

13/ Appendix E, "Navigation", prepared by the U. S. Army Engineer District, Philadelphia, Department of the Army

VII QUALITY CHECKS ON PROJECTIONS

42. Comparison with Other Methods. Prior to the adoption of the projection procedures described in this appendix, several tentative projections of gross water needs were made. Basically, these projection methods separated domestic-municipal use from industrial use. For domestic and municipal use, assumed per capita use rates were applied to population projections. For industrial use, assumed per employee use rates were applied to employment and projections. Results of four methods using different assumptions or different combinations of use categories are compared with the adopted projections for the Delaware River basin as a whole as shown on plate 10. These methods are designated (a), (b), (c), and (d).

a. Method (a) projected municipal water and self-supplied industrial water separately. A rate of increase of 2% per year was assumed for projection of municipal per capita use. The per employee rate of use for industrial water was assumed to double by 2010.

b. Method (b) projected domestic municipal water, exclusive of industrial water supplied from municipal sources, with per capita use increasing at 1.5% per year. Municipally supplied industrial water was assumed to increase at the rate of 3.5% per year on a per employee basis. Per employee use of self-supplied industrial water was assumed to double by year 2010.

c. Method (c). Similar to method (b) for domestic-municipal water. All industrial water combined in a single projection with per employee use doubling by 2010 as in method (a).

d. Method (d). A combined projection of domestic-municipal and self-supplied industrial water was made on a per capita basis with a rate of increase of 2% per year.

These methods were used primarily for general order of magnitude estimates. Inspection of plate 10 shows how widely different results can be obtained by variations in the assumptions. The adopted projections relating domestic and municipal per capita use rates to per capita personal income and gross industrial water use to civilian earnings in manufacturing indicate growth rates of 1-1.5% per year in per capita use of domestic and municipal water and about 4% per year in per employee use of industrial water with some variation among subregions. The adopted procedures thus indicated that the preliminary assumptions pertaining to growth rates in the early projections were generally of the right order of magnitude, while adding the flexibility of recognizing varying growth rates among subregions and providing an objective means of estimating them.

43. Comparison with Other Projections for Pennsylvania Portion of Basin. Portions of Pennsylvania are found in subregions C, E and G. Considering only those counties within the confines of the Delaware River basin, the following distribution of 1955 populations is noted:

TABLE P-9

PERCENT OF PENNSYLVANIA POPULATION IN SUBREGIONS IN 1955

Subregion	Population - 1000's		Percent of Subregion
	Subregion	Pennsylvania	
C	798	696	87.2
E	4,121	3,508	85.1
G	551	327	59.3

From the above percentage distribution, Pennsylvania portions of projected populations and water use were obtained from subregions C, E, and G, for the domestic and municipal water use category. These projections are compared on plate 11 with those furnished by the Commonwealth of Pennsylvania. It should be noted that the projections of this appendix include populations in the self-supplied domestic water use category while those of Pennsylvania represent populations served from municipal systems only. The plate contains three figures, one for population, one for water use, and one for per capita use. Populations based on Office of Business Economics projections are in approximate agreement in 1955 but diverge from the Commonwealth's projections over the projection period with the former being about 40% higher in 2010. Base-water use is about the same in both methods with the method of this appendix indicating an increasingly higher magnitude than Pennsylvania's projection amounting to 60% by 2010. The per capita use rates are approximately the same with minor divergence. In general, Pennsylvania's projections of gross water needs for domestic and municipal use are satisfied by the adopted projections. Specific projections by and for the City of Philadelphia from Appendix C are also shown on plate 11 for comparative purposes.

44. Comparison with Other Projections for New York City Area. Independent projections of water use for the municipal needs of New York City are presented and discussed in section 14, Appendix C. Comparison of these projections is made on plate 12 with the domestic and municipal projections of this appendix for subregions A and B, the New York City metropolitan and supplementary areas. The most striking difference appears to be in the levels of per capita consumption in the near future. These may be reconciled, however, by the fact that the lower subregion rates reflect the lack of mun-

icipal-industrial use in outlying areas. The projections of New York City appear to be reasonable. The Supreme Court Decree of 1954 authorizes New York City to divert a maximum of 800 MGD from headwaters tributaries of the Delaware River. Construction of reservoirs for this diversion has been or is now in progress of completion. While New York City has indicated a possible projected need for an additional 400 MGD by 2010, the question of provision for this need from Delaware River basin sources or other sources available to New York City outside the basin is beyond the scope of the present investigation.

45. Comparison with Other Projections for the State of Delaware. Comparisons between projections by the State of Delaware for New Castle county and those by the method of this appendix may be made by isolating the approximate New Castle share of projections for subregion F. On the basis of a fairly stable relation between the population of New Castle county and subregion F as shown in figure 1, plate 13, domestic and municipal water use projections for subregion F were apportioned to New Castle county by the ratio of the 1955 water use data. Figure 2, plate 13, shows the New Castle average water use as obtained from 68% of the subregion use in comparison with 30-day maximum domestic use given by the State of Delaware. A straight line was drawn through Delaware's water use data for 1958 and 2010 since projections for the intermediate years were not given in Appendix O. No comparison is made with Delaware's projections beyond 2010. It may be seen by these comparisons for New Castle county that the projections of this appendix are in reasonably close agreement with those of the State of Delaware. More important for this area than projections of gross water needs are projections of fresh water needs. The latter are discussed in paragraph 55.

VIII NET WATER NEEDS

46. General Relation of Gross Needs to Streamflow. The procedures described thus far have been concerned with the estimation of gross water needs in problem areas. These needs are "gross" in the sense that they represent total withdrawal requirements from all sources. The actual quantities of streamflow which must be made available, however, are related only to the gross surface water needs. Furthermore, the actual net streamflow needs will be somewhat less than the gross surface needs due to natural and cultural conservation effects such as available minimum flows and augmented flows from existing projects or projects currently under construction.

47. Re-use. In the course of its flow from headwaters areas to the sea, water may be withdrawn from streams, used, returned to streams and re-used repeatedly. Studies of water withdrawals in some areas indicate pumping rates many times the natural minimum flow of the supplying stream. This re-use of water serves to make the actual streamflow requirements less than the gross water usage. Re-use of industrial water in the Delaware River water service area is a fundamental consideration in water resource planning. In the interests of conservatism, repetitive use of water was assumed only in the estimation of industrial water forecasts in relatively well developed industrial areas, namely, the Lehigh River area, the Upper Schuylkill River area, and the Trenton-Philadelphia area. A comparison of present water use and minimum flow in the Lehigh River area indicates that the current industrial water requirements are about twice the current minimum flow after allowance for domestic, municipal and agricultural use. This corresponds to one repetition of use after the first use. Re-use in the Lehigh is expected to grow to about four times by 2010. In the Upper Schuylkill area where no reuse is apparent at present, a re-use of 1.0 was assumed in 2010. In the Trenton-Philadelphia area present re-use is zero and is expected to be 3.6 by 1980. Re-use factors are shown on line (9) of table P-10. These re-use factors serve as an index of the relative multiple use to which surface flows can be put.

48. Consumptive Losses and Returns. A study of consumptive loss rates in various sections of the United States indicates that average consumptive losses are about 5 to 10% of the total water use. Thus 90 to 95% of surface water withdrawals are returned to stream channels and are available for downstream users. In areas not served by municipal systems a small percentage (30%) of ground water also finds its way back to streams by percolation through the soil. In municipal areas 95% of domestic water use

served from ground water is returned through municipal sewage systems whose effluent empties into stream channels. Returns to surface flow after industrial ground-water use were put at 90 to 95% of industrial ground-water use.

49. Effective Use Factor. If the percent of consumptive loss is designated by the letter L, the return after the first use is (1 - L) for unit demand. With a one time re-use the return is then $(1 - L)^2$, a two time re-use $(1 - L)^3$, etc., etc. to $(1 - L)^{(n + 1)}$ for n repetitions of use. With no re-use, the effective use is 1.0 and the required flow must equal the demand. With L = .05 a one time re-use, the effective use is not quite twice the supply since the second use supplies only 95% of the first use. The effective use is thus $1 + (.95)^{1.0} = 1.95$. With two repetitions of use after the first use, the effective use would be $1 + .95 + (.95)^2$ etc., to + ... $+ (.95)^n$ for n repetitions of use. For continuity, the above series may be represented by the integral, $\int_0^n (1 - L)^n dn$ which is solved on plate 14. The effective use factors indicate the multiple quantity of demand which may be satisifed by a unit quantity of water with the number of indicated repetitions of use and with allowance for a continuous consumptive loss throughout all use. With a given number of repetitions of use, then, the net flow required to meet a given demand is obtained by dividing the gross demand by the effective use factor. In the Lehigh River area, for example, the gross industrial surface water demand in 2010 is 1,566 MGD. From the curve of plate 14, a re-use of 4 indicates an effective use factor of 4.3. The flow required to supply a demand of 1,566 MGD is therefore 1566/4.3 = 364.2 MGD. These computations are indicated in detail in table P-10. In the computation of net surface flow requirements the gross surface water demands for domestic-municipal use were computed separately from those for self-supplied industrial use to allow for differences in ground-water return and re-use. The application of return and re-use just described has been limited to domestic-municipal and self-supplied industrial water uses only. The quantities of water for irrigation, rural and livestock use are relatively small by comparison and full provision will be made for these gross demands without reduction for return and re-use. The indicated net flow requirements for irrigation, livestock and other rural uses are therefore set equal to the gross surface demand as shown on line (12), table P-10.

50. Estimates of Net Surface Needs. The net surface flow requirements then are indicated for all uses on line (13) of table P-10. The remainder of the table is devoted to computation of net surface flow augmentation requirements. Consideration is given here to minimum available surface flows and returns from upstream sources. Minimum flows are shown on line (16) of table P-10. Where minimum flows are far in excess of the demand, an asterisk appears instead of the flow. Where augmentation of flow is needed the minimum flows are shown and the difference between the net surface need and minimum flow is computed and shown on line (17), table P-10.

	UPPER DELAWARE				MIDDLE DELAWARE				
	1955	1965	1980	2010	1955	1965	1980	2010	1955
DOMESTIC AND MUNICIPAL 1/									
(1) Gross Surface	13.9	20.0	27.6	49.0	4.5	6.0	8.3	15.4	34.9
(2) Gross Ground	4.0	4.4	5.9	10.0	3.9	4.9	6.5	10.7	17.0
(3) Other	8.2	9.1	12.1	20.4	4.1	4.9	6.7	11.0	9.0
(4) Return from "other"	2.5	2.7	3.6	6.1	1.2	1.5	2.0	3.3	2.7
(5) Net surface need (1) - (4)	11.4	17.3	24.0	42.9	3.3	4.5	6.3	12.1	32.2
SELF SUPPLIED INDUSTRIAL 1/									
(6) Gross Surface	8.0	12.3	18.3	38.3	21.0	29.1	43.1	94.2	347.0
(7) Gross Ground	1.0	1.4	1.8	3.0	10.0	12.8	16.2	24.5	20.0
(8) Consumptive loss, L, %	5.0	5.0	5.0	5.0	10.0	10.0	10.0	10.0	10.0
(9) Re-use	0	0	0	0	0	0	0	0	1.05
(10) Effective use 2/	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	2.00
(11) Net surface need (6) / (10)	8.0	12.3	18.3	38.3	21.0	29.1	43.1	94.2	173.5
AGRICULTURAL 1/									
(12) Net 3/	1.4	3.3	3.9	4.0	Incl. in Trenton-Phila.				0.5
NET SURFACE NEEDS ALL USES									
(13) (5) + (11) + (12)	20.8	32.9	46.2	85.2	24.3	33.6	49.4	106.3	206.2
(14) Upstream surface loss 4/									
(15) Net adj. for upstream loss	20.8	32.9	46.2	85.2	24.3	33.6	49.4	106.3	206.2
AUGMENTATION REQUIREMENTS 5/									
(16) Minimum surface flow 6/	*	*	*	*	*	*	*	*	206.5
(17) Augmentation req. (15) - (16)	0	0	0	0	0	0	0	0	0

1/ Gross water needs from Table P-8

2/ Re-use is the number of repetitions of use after the first use. Relation of effective use to

3/ Net surface needs equal gross surface needs for agricultural use.

4/ Applicable to Trenton-Philadelphia area only. Represents consumptive loss from all domestic-

5/ Refer to Plates 15, 16, 17, and 18 for graphical representation of gross and net surface wate

6/ Minimum surface flows are taken from daily flow-duration curves at 95%. Minimum flow in Tren

TABLE P-10. COMPUTATION OF NET SURFACE WATER REQUIREMENTS IN PROBLEM AREAS

(All water quantities in million gallons per day)

LEHIGH			UPPER SCHUYLKILL				TRENTON-PHILADELPHIA				WILM	
1965	1980	2010	1955	1965	1980	2010	1955	1965	1980	2010	1955	1965
44.6	62.8	115.8	41.1	55.5	76.9	139.3	475.0	597.6	830.6	1,471.7	33.3	50.2
20.6	27.4	45.6	9.1	10.9	14.5	24.2	72.8	85.8	109.6	157.0	7.2	10.8
11.1	14.8	24.6	8.1	10.0	13.3	22.0	39.0	46.2	59.4	86.5	4.6	6.7
3.3	4.4	7.4	2.4	3.0	4.0	6.6	11.7	13.8	17.8	25.9	1.4	2.0
41.3	58.4	108.4	38.7	52.5	72.9	132.7	463.3	583.8	812.8	1,445.8	31.9	48.2
485.4	719.8	1,566.0	82.0	123.3	183.9	385.6	1,156.7	1,541.7	2,224.9	4,623.3	206.0	933.0
25.6	32.4	49.4	28.0	39.1	50.5	81.1	94.3	118.3	155.1	257.7	16.0	67.0
10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
1.63	2.44	4.06	0	0	0.20	1.00	0	0.50	1.00	3.60	0	0
2.50	3.15	4.30	1.00	1.00	1.20	1.95	1.00	1.49	1.95	4.00	1.00	1.00
194.0	228.5	364.2	82.0	123.3	153.3	197.7	1,156.7	1,034.7	1,141.0	1,155.3	206.0	933.0
2.4	2.8	2.9	Incl. in Trenton-Phila.				4.8	19.3	24.4	24.4	1.6	12.1
237.7	289.8	475.5	120.7	175.8	226.2	330.4	1,624.8	1,637.8	1,978.2	2,626.0	239.5	993.3
							196.3	279.7	399.4	789.7		
237.7	289.8	475.5	120.7	175.8	226.2	330.4	1,821.1	1,917.5	2,377.6	3,415.7	239.5	993.3
206.5	206.5	206.5	190.0	190.0	190.0	190.0	1,915.0	2,060.0	2,060.0	2,060.0	100.0	100.0
31.2	83.3	269.0	0	0	36.2	140.4	0	0	317.6	1,355.7	139.5	893.3

to re-use is given on Plate 11.

ic-municipal, industrial, and agricultural surface uses. See para 54.

ater needs, surface flow augmentation requirements and indication of storage potentials in critical problem ar

renton-Philadelphia area adjusted for operation of NYBWS reservoirs in accordance with Supreme Court Decree of

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AREAS

	PHILADELPHIA		WILMINGTON				SOUTHERN BASIN & COASTAL			
	1980	2010	1955	1965	1980	2010	1955	1965	1980	2010
	830.6	1,471.7	33.3	50.2	75.0	157.2	6.4	8.7	12.5	16.1
	109.6	157.0	7.2	10.8	15.5	30.4	24.3	36.7	63.7	136.0
	59.4	86.5	4.6	6.7	10.0	19.4	14.4	21.8	37.8	80.9
	17.8	25.9	1.4	2.0	3.0	5.8	4.3	6.5	11.3	24.2
	812.8	1,445.8	31.9	48.2	72.0	151.4	2.1	2.2	1.2	0
7	2,224.9	4,623.3	206.0	933.0	1,549.0	2,744.0	6.0	10.0	15.0	32.0
3	155.1	257.7	16.0	67.0	101.0	141.0	27.0	42.0	72.0	173.0
0	10.0	10.0	10.0	10.0	10.0	10.0	5.0	5.0	5.0	5.0
50	1.00	3.60	0	0	0	0	0	0	0	0
49	1.95	4.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
7	1,141.0	1,155.3	206.0	933.0	1,549.0	2,744.0	6.0	10.0	15.0	32.0
3	24.4	24.4	1.6	12.1	14.6	14.6	5.0	8.0	9.4	10.0
8	1,978.2	2,626.0	239.5	993.3	1,635.6	2,910.0	13.1	20.2	25.6	42.0
7	399.4	789.7								
5	2,377.6	3,415.7	239.5	993.3	1,635.6	2,910.0	13.1	20.2	25.6	42.0
0	2,060.0	2,060.0	100.0	100.0	100.0	100.0	*	*	*	*
	317.6	1,355.7	139.5	893.3	1,535.6	2,810.0	0	0	0	0

rage potentials in critical problem areas.

ccordance with Supreme Court Decree of 1954. *Minimum flow exceeds demand.

IX AREAS OF INDICATED SURFACE WATER DEFICIENCIES

51. Water Deficient Areas. By inspection of line (17), table P-10, it is seen that four areas will require augmentation of their surface flows to provide the indicated net surface water needs. These are areas of indicated deficiencies of surface waters and are examined separately with respect to storage reservoirs or other potential means of providing the required flow augmentation. The deficient areas are the Lehigh, the Upper Schuylkill, Trenton-Philadelphia, and Wilmington.

52. Lehigh Area. The relation of gross and net surface water needs in the Lehigh area is shown in figure 1, plate 15. The top curve shows the gross needs for all uses from all sources. The cross hatched area indicates the portion of gross needs to be met from ground-water sources. The middle curve thus represents the gross surface water needs for all uses. The bottom curve represents the net surface water needs which will be required to supply all the gross surface needs with effective use taken into account and represents the net surface needs indicated on line (15), table P-10. This same curve is reproduced on an expanded scale in figure 2, plate 15, for examination with respect to storage potentials. The minimum flow at Bethlehem is 206 MGD which is just capable of satisfying the 1955 demand. A severe drought in this area may require temporary water conservation measures to avoid possible serious effects on the local economy during the drought period. A drought of lesser magnitude occurred in 1957 imposing some curtailment of industrial activity for lack of sufficient water. Thus, early augmentation of flow in the Lehigh area is indicated. By 2010 the augmentation required will be about 270 MGD. Aquashicola reservoir, with a storage of 30,000 acre-feet, would augment the flow of the Lehigh River by 45 MGD and provide a level of minimum flow at Bethlehem which would sustain the net surface needs to 1970. Trexler reservoir, with 24,000 acre-feet storage, could add 32 MGD to keep pace with the rising surface needs until 1980. Tobyhanna, with 85,000 acre-feet, or equivalent storage in Bear Creek reservoir, would provide an increment of 145 MGD which, as seen in figure 2, would satisfy Lehigh needs to 2,004. Finally, the increment of 43 MGD from Beltzville reservoir, with 24,000 acre-feet, would complete the storage reservoir program for meeting the 2010 surface needs. The suggested storages and indicated sequences of construction is shown for illustrative purposes only. Any rearrangement of the four projects or sutiable alternates capable of producing equivalent combined net yields will satisfy the 2010 augmentation requirement.

53. The Upper Schuylkill Area. As described for the Lehigh area, figure 1, plate 16, shows the gross and net water needs for the Upper Schuylkill area. Similarly figure 2, plate 16, shows the net surface needs and the 190 MGD minimum flow at Pottstown. This minimum flow is adequate for Upper Schuylkill needs until 1969. After that time, an augmentation requirement of 140 MGD will be needed to supply this area's needs by the end of the projection period. Two reservoirs, namely Bernville and Blue Marsh, or suitable alternate, and Maiden would have sufficient yields to provide these augmentation requirements. Bernville or Blue Marsh, with a net yield of 60 MGD could satisfy Upper Schuylkill needs to 1987 and Maiden, with an incremental yield of 84 MGD, would provide the remainder of the augmentation requirement to 2010. A reversal of these projects or any alternate combination of storages which will provide the 2010 augmentation requirement of 140 MGD will satisfy the projected needs of this area providing attention is given to the timing as indicated by the net surface water demand curve.

54. Trenton-Philadelphia. Figure 1, plate 17, shows the gross and net water needs for the Trenton-Philadelphia area. Net surface needs and minimum available flow are shown in figure 2 from data on line (15), in table P-10. These have been adjusted for upstream losses to facilitate integration of returns from upstream augmentations with additional augmentation requirements in this area. The minimum flow shown represents the combined minimum flows of the Schuylkill River at Philadelphia and the Delaware River at Trenton. The Trenton minimum flow is adjusted for operation of the Pepacton and Neversink to 1965 and both of these plus Cannonsville after 1965 according to the Supreme Court Decree of 1954. In this area the net 2010 augmentation requirement will be 1,356 MGD, of which 144 MGD will be provided from Upper Schuylkill reservoirs and 265 MGD from Lehigh reservoirs, leaving a remainder of 947 MGD to be provided from additional storage sources. Tocks Island reservoir and Hawk Mountain reservoir can provide a combined yield of 949 MGD which will be adequate to round out the program. Using the hypothetical timing of Lehigh and Upper Schuylkill reservoirs suggested in plates 15 and 16 it can be seen by reference to figure 2, plate 17, that storage would be needed for additional augmentation of flow in the Trenton-Philadelphia area by 1976. With 633 MGD from Tocks Island and subsequent increments in the Lehigh and Upper Schuylkill area, the needs of this area are met to 2000. At that time, Hawk Mountain with a net yield of 316 MGD would then provide the remaining augmentation requirement to 2010. The Hawk Mountain yield increment has been suitably adjusted to allow for the reduction in yield from Tocks Island caused by the regulatory effect of Hawk Mountain on inflow to Tocks Island after Hawk Mountain is put into operation.

55. Wilmington. The Wilmington area approaches the small local area whose water needs fall more into category of spot requirements rather than the broad generalized water needs of the rest of the basin. The impact of the new Tidewater Oil Company plant on industrial water use is clearly seen by the unusual change of the Wilmington area's self-supplied industrial needs from 1955 to 1965. In the case of this area, the 1957 industrial water use, reflecting the additional water needs of the new plant, was used as the projection base for the later years. It is pointed out, however, that such an intermediate adjustment is contrary to the generalized projection approach and was made here only because the magnitude of the change was large in relation to the demands of the area. For the larger areas, however, it is expected that such industrial growth is in the normal course of development and provision for such growth has been adequately covered in the population and personal income projections furnished by the Office of Business Economics. The Wilmington area is further distinguished by its use of the brackish waters of Delaware Bay for a large portion of its self-supplied industrial needs. Because of the heavy concentration of industrial users in the vicinity of Wilmington, industrial water returns have been assumed as direct discharge to the bay and are therefore not available for re-use. The effective use factor was consequently put at 1.00 for this area and the net surface need for self-supplied industrial use is the same as the gross surface need, lines (6)and(11) table P-10. The augmentation requirements for the Wilmington area, shown on line (17), table P-10, indicate surface water requirements for all uses after allowance for 100 MGD of available flow in the Christina River. The quantities shown here include supplies to be obtained from brackish sources. The brackish supplies are used mainly for industrial cooling water, flushing, and firefighting. However, the method of this appendix projects self-supplied industrial water use without regard to the specific internal industrial application. Therefore, the estimated fresh water needs for the Wilmington area were based primarily on projections for New Castle county as furnished by the State of Delaware and presented in Appendix O. Table VI, page 26-12, of that appendix indicated a 567 MGD requirement for all uses by 2010 exclusive of industrial cooling and steam generation. On the assumption that the latter uses can be supplied from brackish sources, the indicated 567 MGD represents a fresh water requirement. This quantity is a 30-day maximum demand, however, and is equivalent to a 30-day average demand of about 375 MGD. Since New Castle county accounts for about 85% of all fresh water use in the Wilmington area, the 2010 fresh surface water requirements were put at 440 MGD for all of subregion F including both New Castle and Salem counties. An interpolating curve was drawn for intermediate years as shown on figure 1, plate 18. This curve

is reproduced on a larger scale in figure 2 in relation to the 100 MGD minimum flow of the Christina River which comprises all of the Brandywine and White Clay Creek watersheds. This available minimum flow is above the present fresh water needs of the Wilmington area but by 1976 some augmentation of fresh water flow will be required there. The Newark and Christina reservoirs in conjunction with development of the Upper Brandywine by the Commonwealth of Pennsylvania could provide augmentation amounting to 67 MGD which would satisfy the Wilmington area needs to 1986. After that time, consideration would have to be given to other alternatives such as the barrier dam discussed in Appendix S 14/ or diversion from a fresh water reach of the Delaware River. Such additional sources would be required to provide 273 MGD by 2010 for this area.

56. Northern New Jersey. In the consideration of water supplies for New Jersey primary consideration has been given to needs for those areas lying mainly within the Delaware basin boundaries. Cumberland county included in the Upper Delaware area and the counties of Warren and Hunterdon in the Middle Delaware area will have adequate supplies of water in the Delaware River without any specific need for flow augmentation. The counties of Mercer, Burlington, Camden and Gloucester are included in the Trenton-Philadelphia area which is discussed in paragraph 54. The remaining counties, particularly Salem and those in the coastal area, are expected to rely heavily on further exploitation of their groundwater resources. Eight counties of northern New Jersey are included as part of the New York City Metropolitan area and are subject to the same consideration as New York City, namely that allowance is made for diversion of water to these areas from Delaware River basin sources subject to the development of other resources available to them outside the basin. Since it is beyond the jurisdiction of the present investigation to make an evaluation of resources outside the basin, consideration is given only to estimated diversion requirements prepared by the respective states. Under the Supreme Court Decree of June 1954 the State of New Jersey has authority to divert 100 MGD from the Delaware River for out of basin use. The same decree requires New Jersey to provide compensating storage for diversions in excess of 100 MGD. The State of New Jersey has indicated a need for diversion from the Delaware River of 300 MGD to supplement their current development of surface water in the Raritan River basin. Accordingly, provision will have to be made in the final plan of development to allow an additional diversion of 300 MGD to New Jersey by 2010. Reser-

14/ Appendix S, "Salt Water Barrier", prepared by the U. S. Army Engineer District, Philadelphia, Department of the Army.

voir operation studies performed in evaluation of the final plan of development demonstrate how this diversion can be partly satisfied from storage in the Delaware River basin above Riegelsville. See Appendix M 15/ for effects of proposed plan of development.

15/ Appendix M, "Hydrology", prepared by the U. S. Army Engineer District, Philadelphia, Department of the Army

X SUMMARY

57. This appendix has reviewed methods of projecting water demands, has indicated a method of projecting per capita rates of domestic and municipal water use in relation to per capita personal income, and a method of projecting industrial water use in relation to personal income derived from heavy water using industries. Projections of gross water demands were made for domestic, municipal, and industrial use with regard to surface and ground-water sources of supply in the economic subregions, (table P-8). Projected subregion gross water demands were translated into problem area demands and reduced to net surface water requirements by making allowance for portions of the demand served from ground water and brackish supplies, consumptive losses, returns of ground water to surface supplies after use and repetitive use of surface water in industry, (table P-10). Net surface water requirements were presented and augmentation requirements were shown in relation to available minimum flows either natural or regulated by existing projects, (table P-10). The Lehigh River, Upper Schuylkill River, Trenton-Philadelphia and Wilmington areas were singled out as areas of deficient surface water supplies for which storage would be needed for augmentation of surface flow (plates 15 - 18). Approximate times were given at which rising demands would exhaust presently available minimum flows and storage potentials to provide needed flow augmentation were indicated. The final selection of projects, storage allocations for water supply, construction schedules, and interactions of water supply with other uses of storage in multiple purpose projects is discussed in Appendix Q 16/. The reliability of any projection diminishes rapidly as the projection period increases and the area decreases. It is generally recognized that even in a projection period as short as ten years and for areas as small as the subregions of this basin, the reliability of projections is doubtful. It is of the utmost importance, therefore, that an intensive continuing survey program of water use be established. With data from such a program, water demand projections could be updated as time goes on to provide increased reliability of water market estimates and indicate the need for reappraisal or confirmation of the adequacy and timing of the proposed plan of development.

16/ Appendix Q, "Formation of the Plan of Development", prepared by the U. S. Army Engineer District, Philadelphia, Department of the Army.

CORPS OF ENGINEERS U.S. ARMY

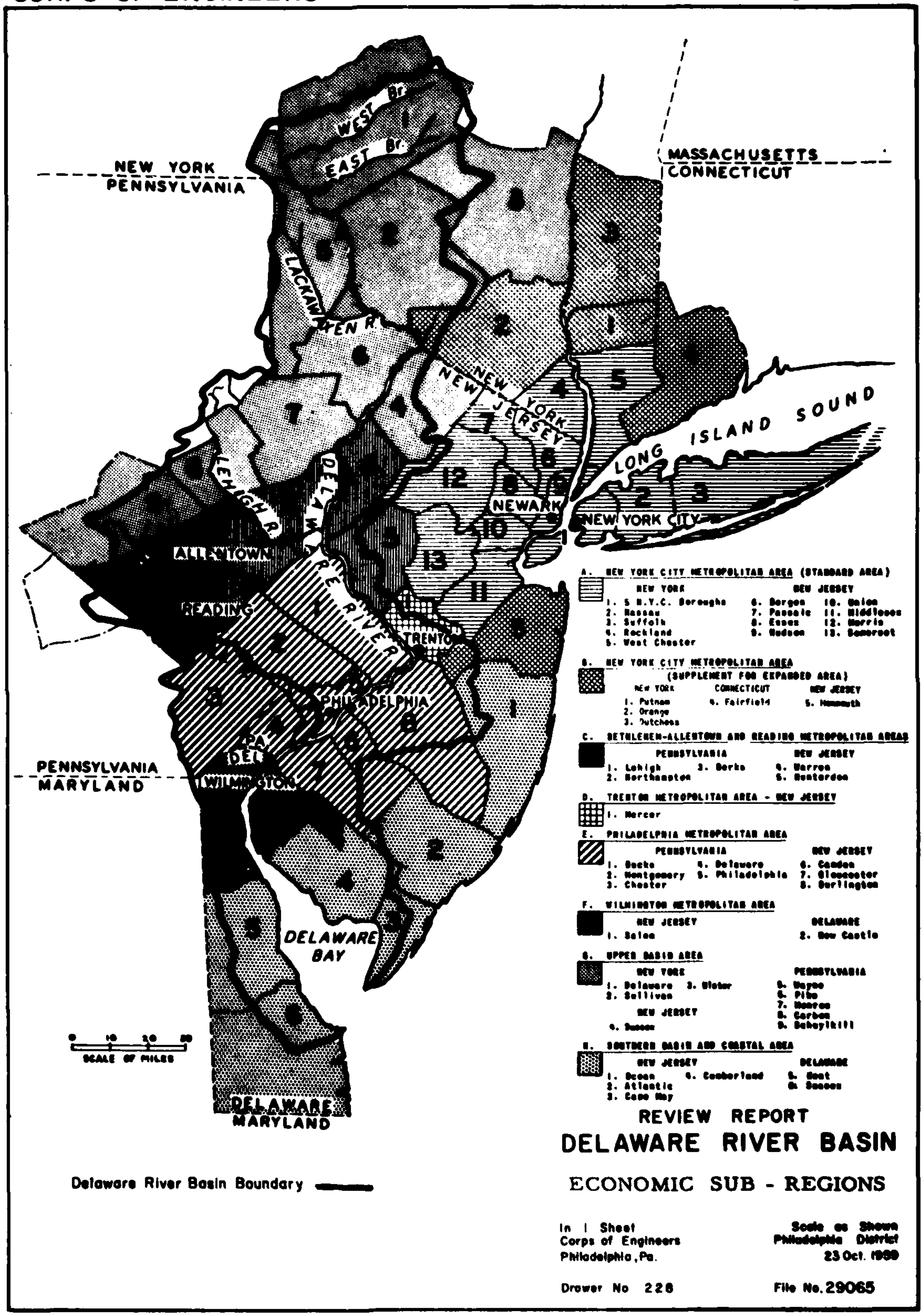


PLATE NO. 1

CORPS OF ENGINEERS U.S. ARMY

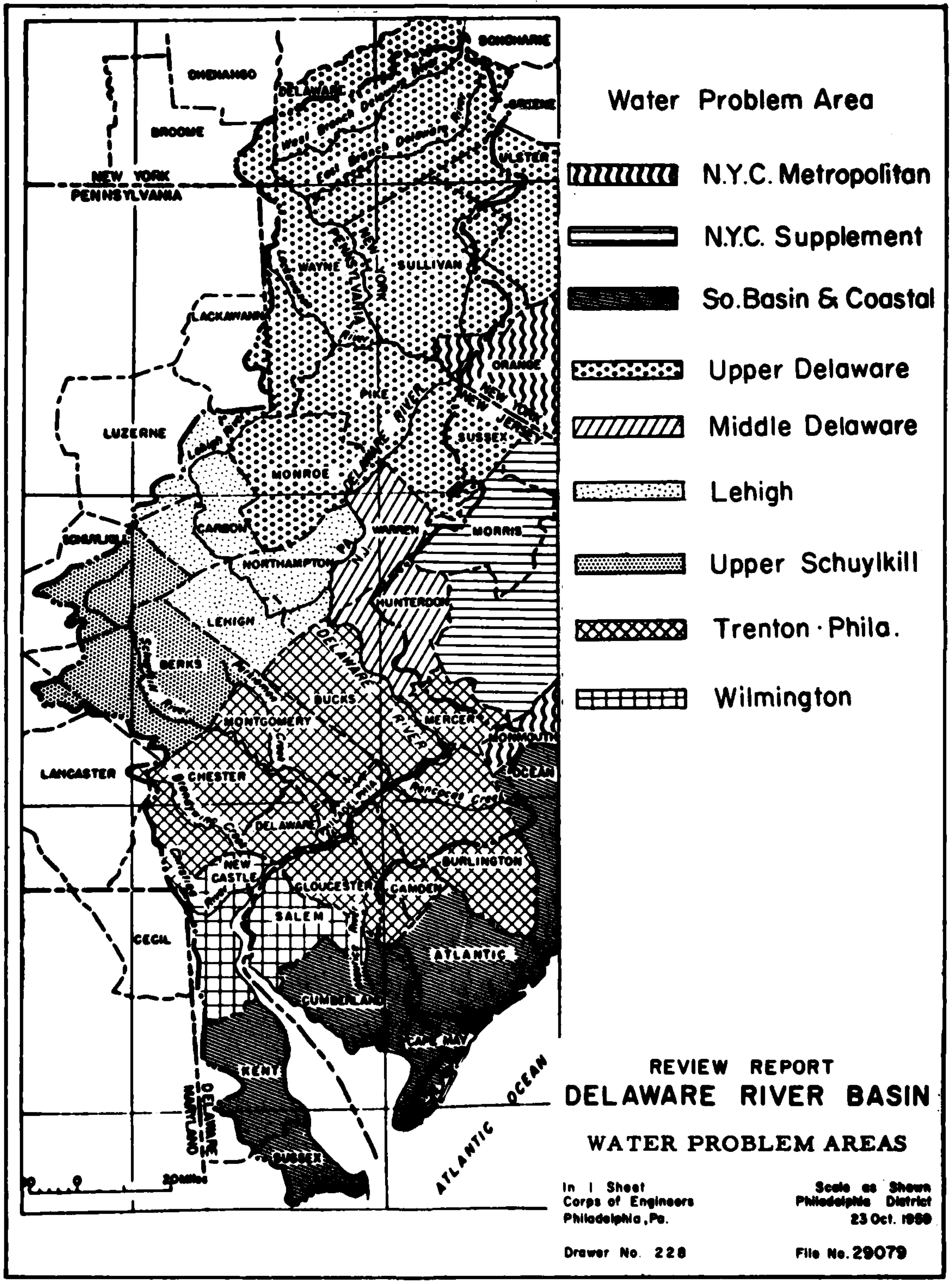


PLATE NO. 2

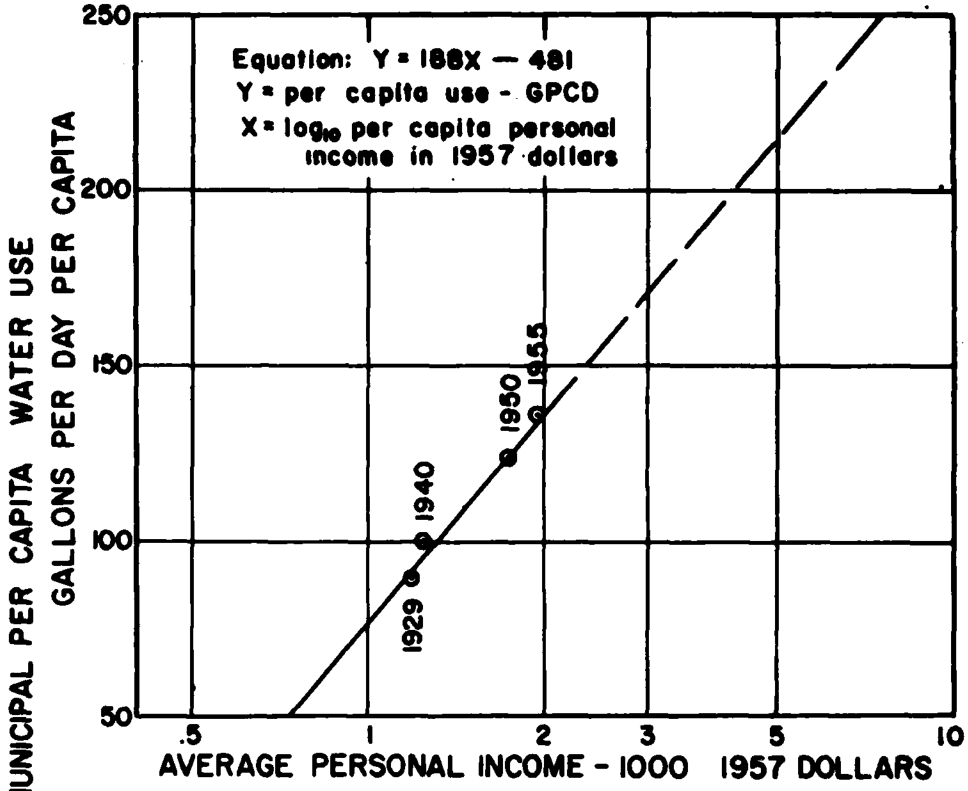


FIG. 1. TREND & PROJECTION OF PER CAPITA WATER USE

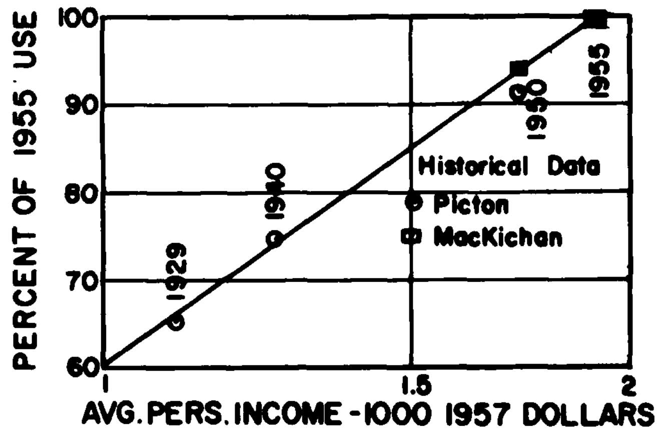


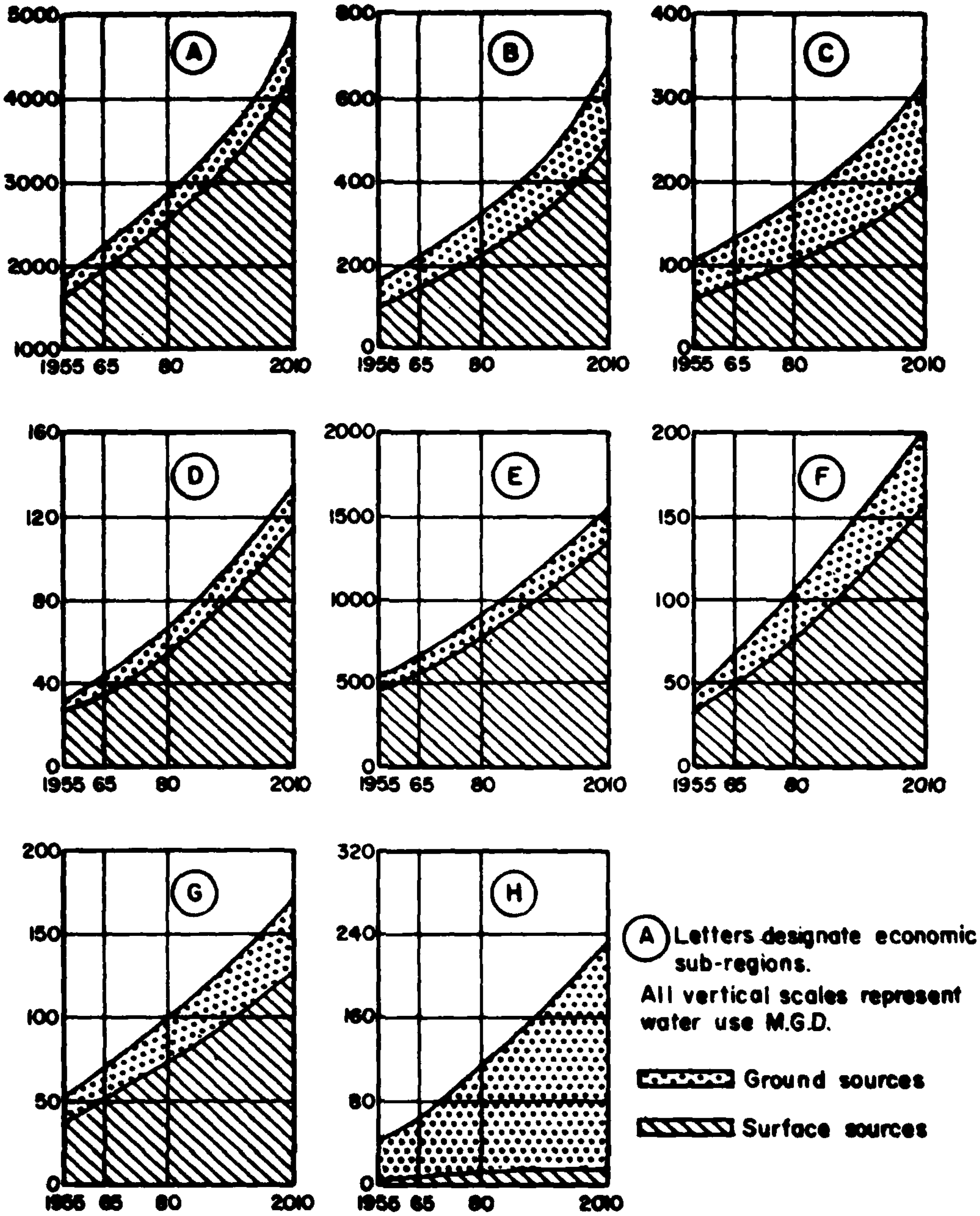
FIG. 2. HISTORICAL PER CAPITA WATER USE

NOTE: MacKichan's data for 1950 & 1955 support trend shown by Picton's data when expressed in percent of 1955 water use.

All data at National level.

Personal Income = per capita income

REVIEW REPORT
DELAWARE RIVER BASIN
PER CAPITA WATER USE
VS. PERSONAL INCOME
In 1 Sheet Scales as Shown
Corps of Engineers Phila. Dist.
Philadelphia, Pa. 30 Sept. 1959
Drawer No. 228 File No. 29066



Note: Water for irrigation, livestock, other rural uses not included. Ground sources include both municipal and "other." See text for definition of use categories, para. 8.

REVIEW REPORT
DELAWARE RIVER BASIN
REGIONAL GROSS WATER NEEDS
FOR DOMESTIC & MUNICIPAL USE

In 1 Sheet Scales as Shown
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Philadelphia, Pa. 28 Sept. 1959

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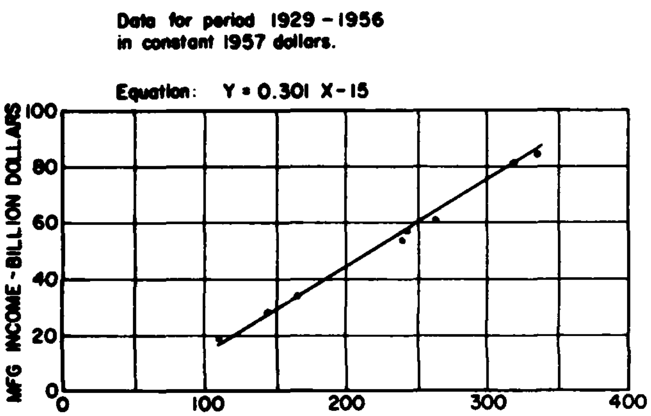

FIG. 1. MANUFACTURING INCOME VERSUS TOTAL INCOME UNITED STATES 1929 - 1956.

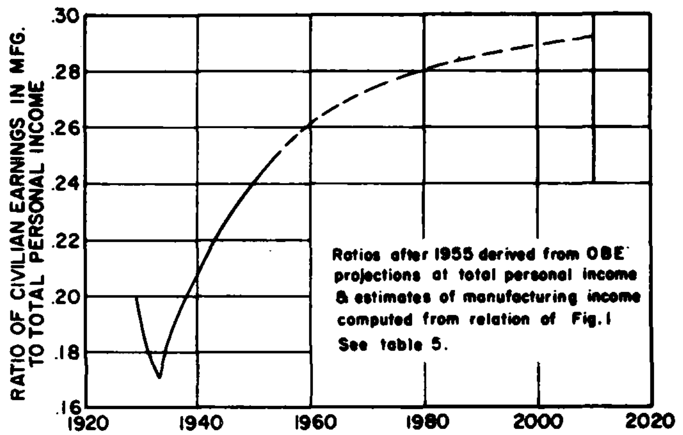

FIG. 2. GROWTH OF MANUFACTURING EARNINGS IN PROPORTION TO TOTAL PERSONAL INCOME UNITED STATES.

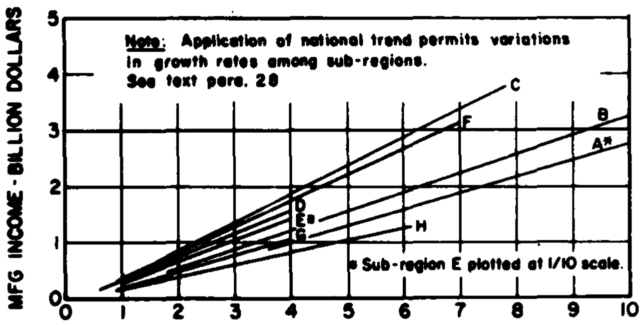

FIG. 3. MANUFACTURING INCOME VERSUS TOTAL INCOME SUB-REGIONS C-H, 1955-2010.

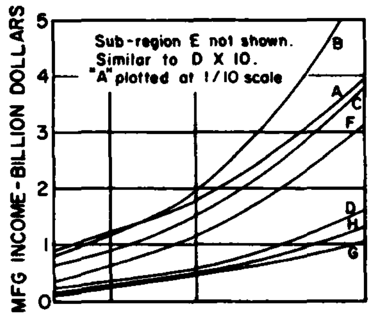

FIG. 4. PROJECTIONS OF MANUFACTURING INCOME IN SUB-REGIONS C-H 1955-2010.

REVIEW REPORT
DELAWARE RIVER BASIN
PROJECTION OF NATIONAL & REGIONAL CIVILIAN EARNINGS IN MANUFACTURING

In 1 Sheet	Scales as Shown
Corps of Engineers Philadelphia, Pa.	Philadelphia District 24 Sept. 1959
Drawer No. 228	File No. 29069

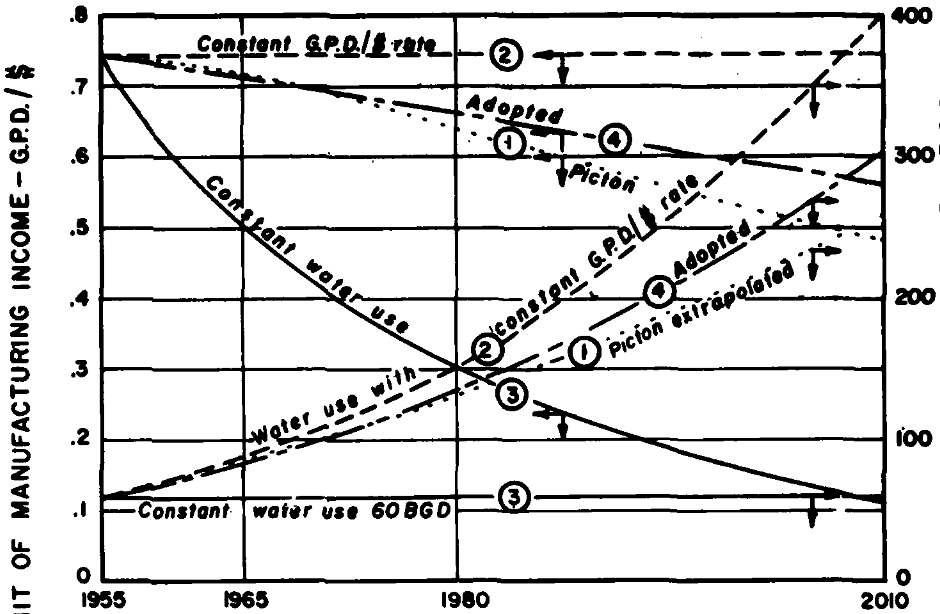

FIG. 1. UNITED STATES

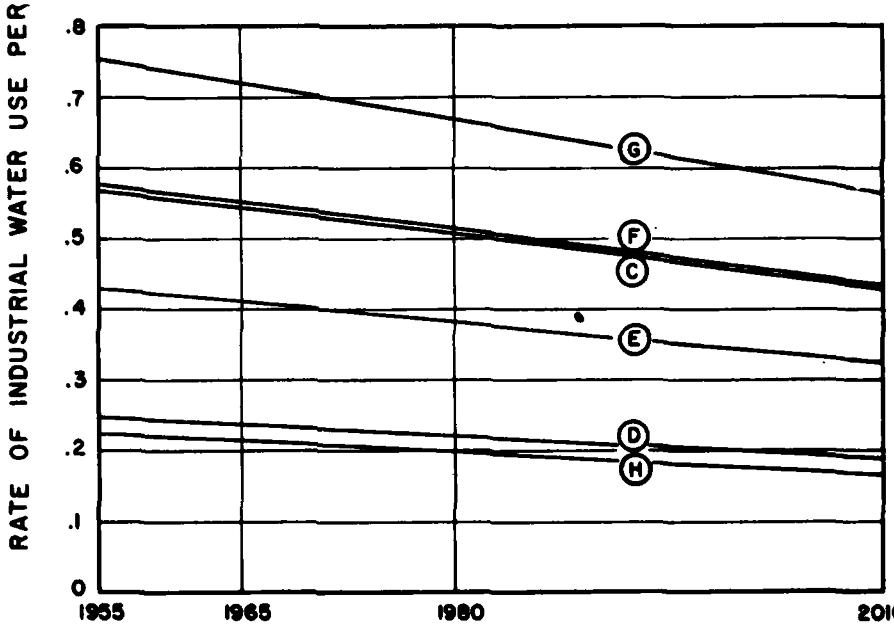

FIG. 2. DELAWARE RIVER BASIN

LEGEND

Ⓒ Letters indicate economic sub-regions. See text para. 30.

REVIEW REPORT
DELAWARE RIVER BASIN
RATE OF INDUSTRIAL WATER USE PER UNIT OF MANUFACTURING INCOME

In 1 Sheet — Scales as Shown
Corps of Engineers — Phila. Dist.
Philadelphia, Pa. — 5 Oct. 1959

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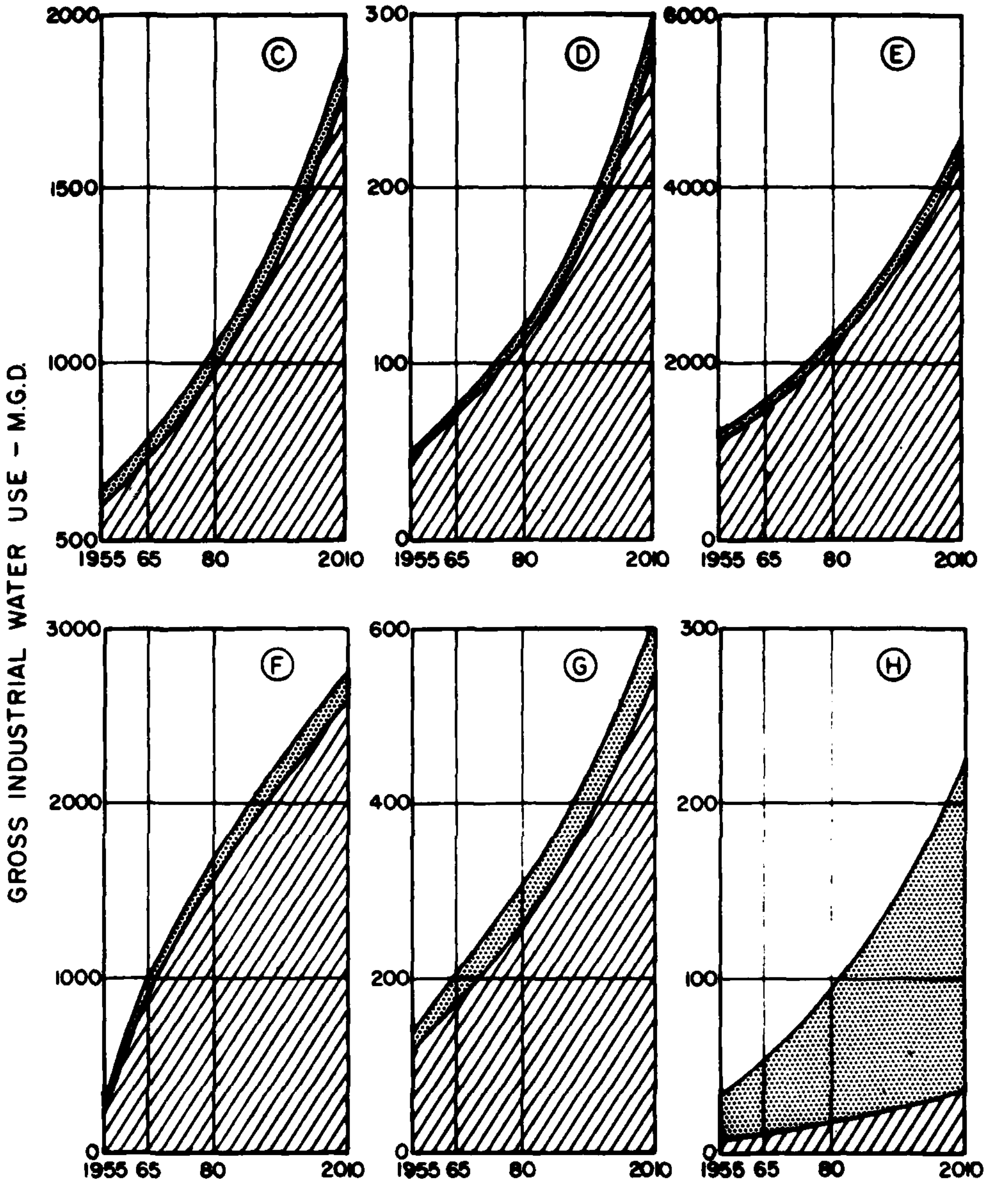

Ⓒ Letters designate economic sub-regions.

All vertical scales represent water use M.G.D.

Ground sources

Surface sources

NOTE: See text para. 31 for projections of industrial water for sub-regions A & B.

REVIEW REPORT
DELAWARE RIVER BASIN
REGIONAL GROSS WATER NEEDS
FOR SELF-SUPPLIED INDUSTRIAL USE

In 1 Sheet Scales as Shown
Corps of Engineers Phila. Dist.
Philadelphia, Pa. 1 Oct. 1959

Drawer No. 228 File No. 29067

CORPS OF ENGINEERS U.S. ARMY

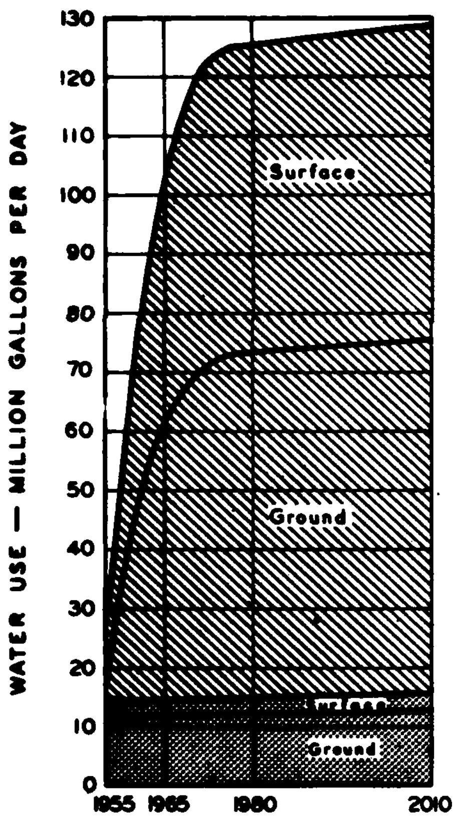

FIG.1. IRRIGATION, LIVESTOCK & OTHER RURAL USES

LEGEND

Irrigation

Livestock

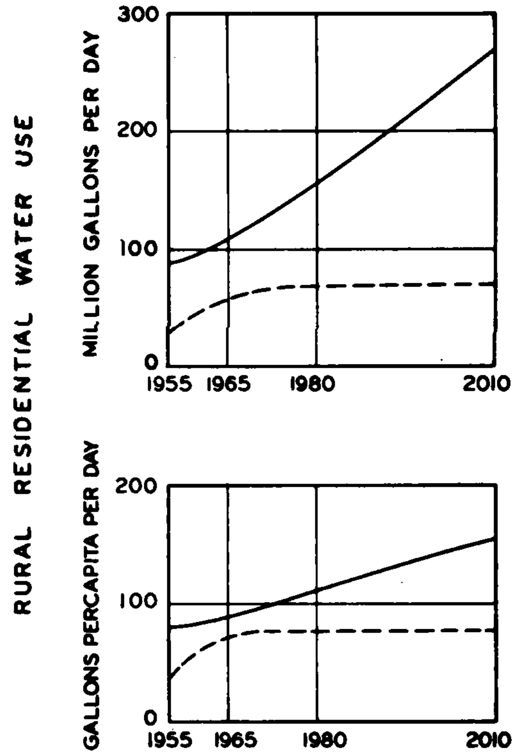

FIG. 2. RURAL RESIDENTIAL USE

LEGEND

—— Standard of living method

- - - Land utilization method

NOTE: U.S.D.A. Projection levels off at 1975 because of population saturation and leveling off of per capita water use rates.

Rural residential water supplied primarily from ground sources.

NOTE: Water use quantities for Delaware River Basin only. Based on data from Appendix G. Excludes Agricultural water use for sub-regions A & B.

REVIEW REPORT
DELAWARE RIVER BASIN

GROSS WATER NEEDS
FOR AGRICULTURE

In 1 Sheet Scales as Shown
Corps of Engineers Phila. Dist.
Philadelphia, Pa. 2 Oct 1959

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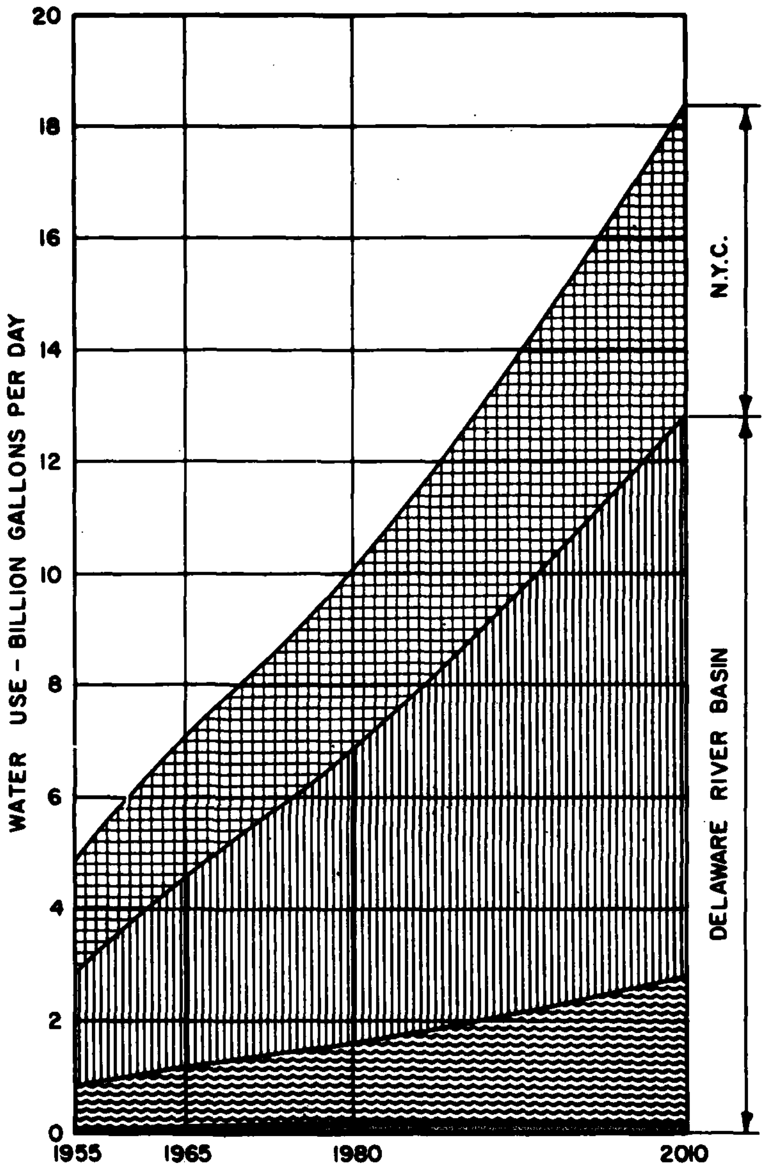

DOMESTIC & MUNICIPAL - N.Y.C. METRO. & SUPPLEMENTARY AREAS (SUB-REGION A & B)

SELF SUPPLIED INDUSTRIAL

DOMESTIC & MUNICIPAL

IRRIGATION, LIVESTOCK, & OTHER RURAL USE

Water needed for thermal - power cooling not included.

REVIEW REPORT
DELAWARE RIVER BASIN
GROSS WATER NEEDS FOR DELAWARE RIVER SERVICE AREA ALL USES

In 1 Sheet Scales as Shown
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Philadelphia, Pa. 2 Oct. 1959

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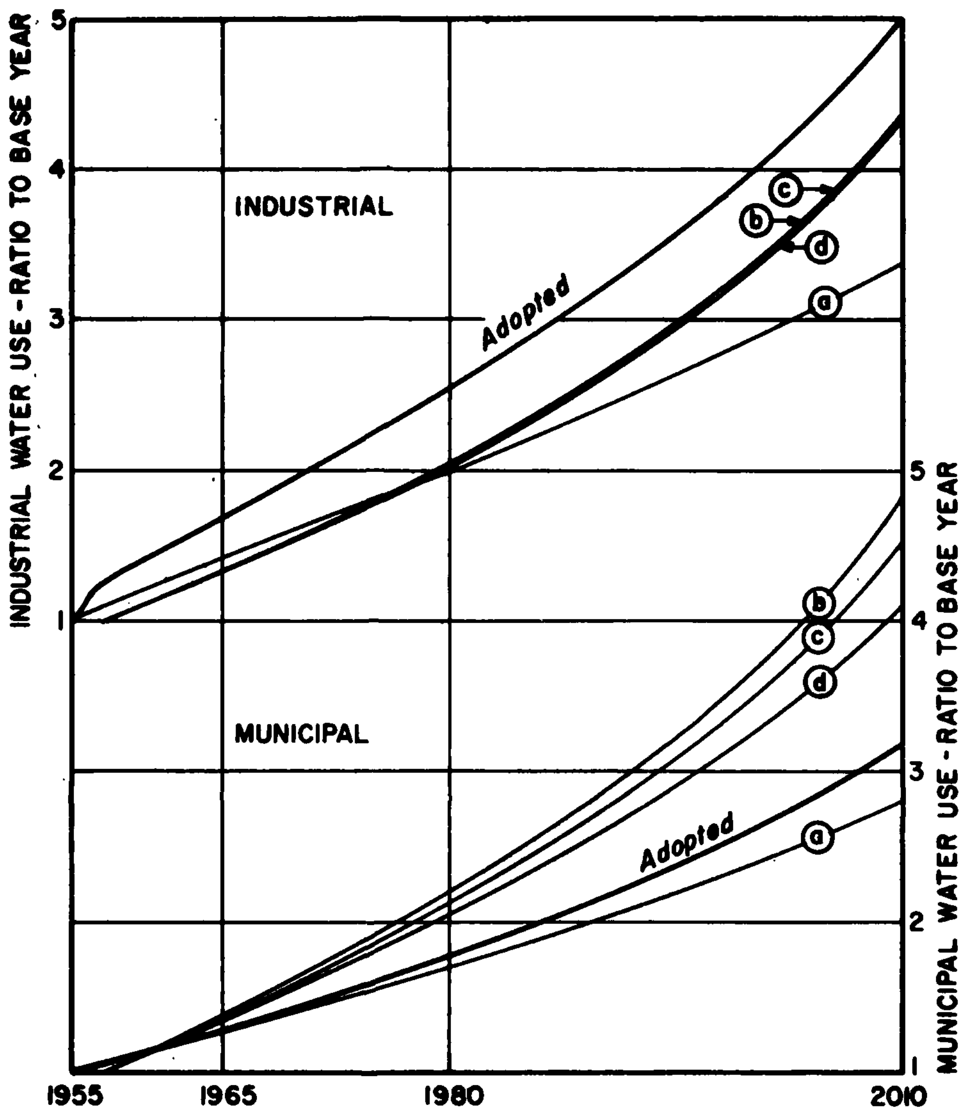

LEGEND:

Adopted

(a) Letters designate alternate methods. See text para. 42.

REVIEW REPORT
DELAWARE RIVER BASIN
GROSS WATER NEEDS
COMPARISON WITH RESULTS OF OTHER METHODS

In 1 Sheet Scales as Shown
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CORPS OF ENGINEERS

U.S. ARMY

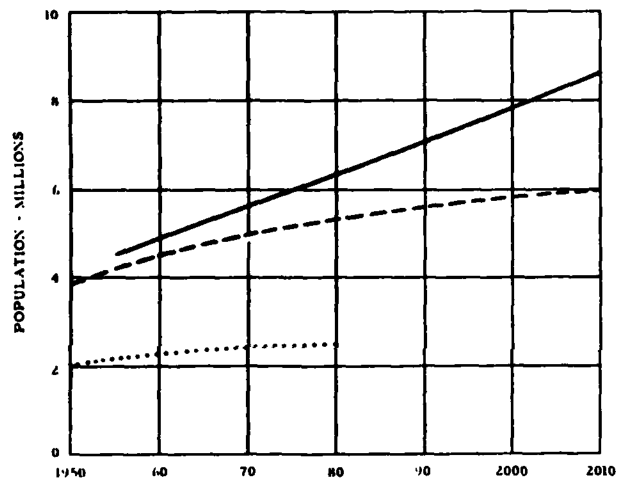

Fig. 1. POPULATION

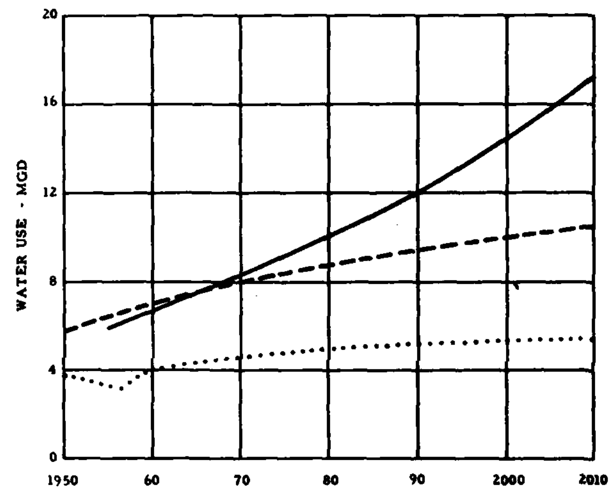

Fig. 2. WATER CONSUMPTION

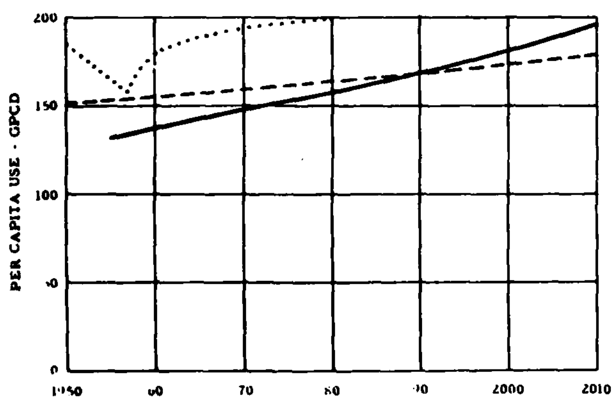

Fig. 2. PER CAPITA WATER USE

LEGEND

——— Adpoted projections } Pennsylvania portion of basin.

— — — Projections by State of Penna. } Pennsylvania portion of basin.

······ Projections for City of Philadelphia from Appendix C, Section VIII.

Pennsylvania projections apply to populations served from municipal sources.

Adopted projections include non-municipally supplied populations.

REVIEW REPORT
DELAWARE RIVER BASIN

GROSS WATER NEEDS
PENNA. PORTION OF BASIN
DOMESTIC AND MUNICIPAL USE

In 1 Sheet
Corps of Engineers
Philadelphia, Pa.

Scale as Shown
Philadelphia District
23 Oct. 1959

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File No. 29074

PLATE 11

CORPS OF ENGINEERS

U.S. ARMY

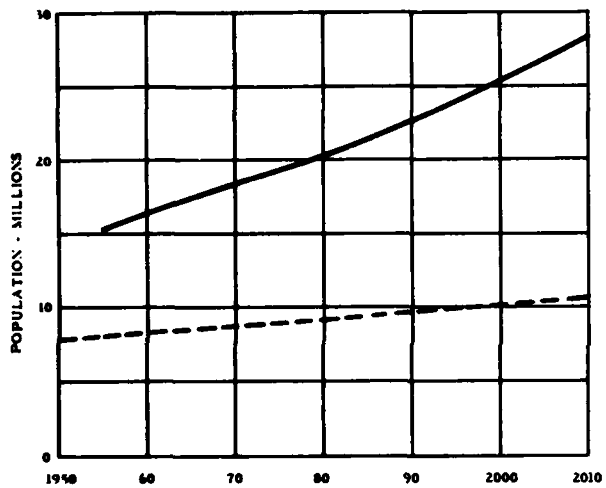


Fig. 1. POPULATION

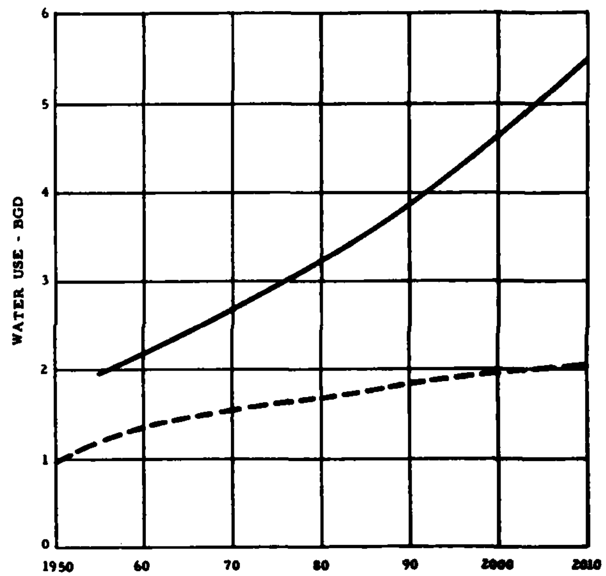


Fig. 2. WATER COMSUMPTION

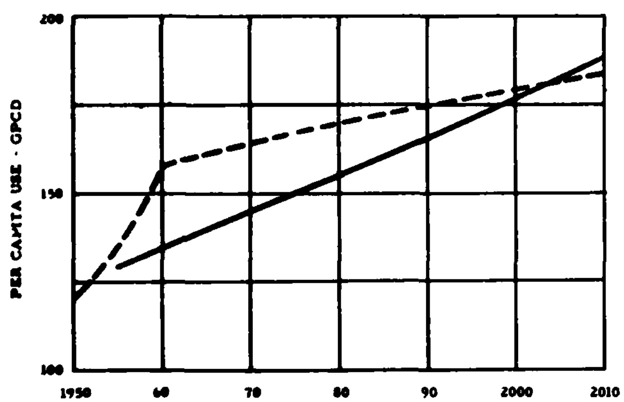


Fig. 3 PER CAPITA WATER USE

— — — Projections furnished by N. Y. C. as published in Section IX, Appendix C.

——— Projections made by the method of this appendix for sub-region A&B.

The rapid rise in per capita consumption indicated by N. Y. C. between 1950 & 1960 is based on data for 1954, 55, 56, & 57.

Lower per capita rates for sub-regions reflect rural use.

REVIEW REPORT

DELAWARE RIVER BASIN

COMPARISON OF MUNICIPAL WATER NEEDS N. Y. C. AND SUB - REGIONS A & B

In 1 Sheet
Corps of Engineers
Philadelphia, Pa.

Scale as Shown
Philadelphia District
23 Oct. 1960

Drawer No. 228

File No. 29075

PLATE 12

CORPS OF ENGINEERS U.S. ARMY

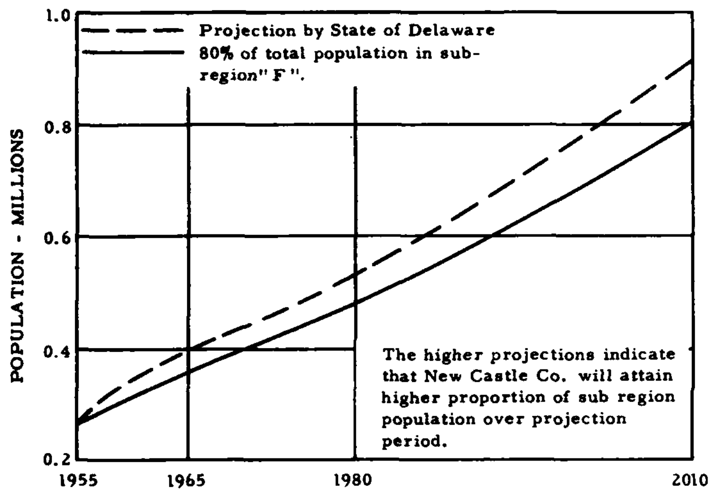


Fig. 1 POPULATION

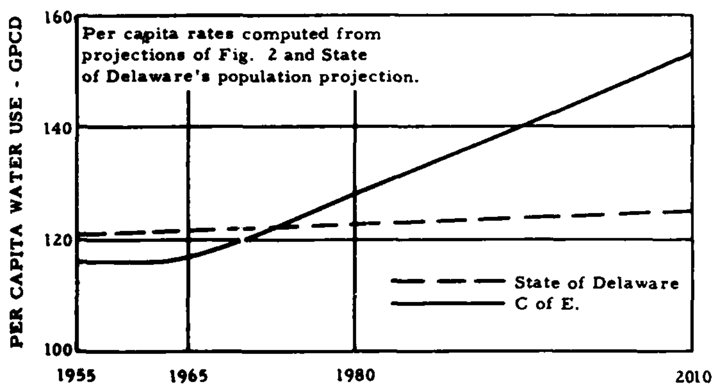


Fig. 3 PER CAPITA USE

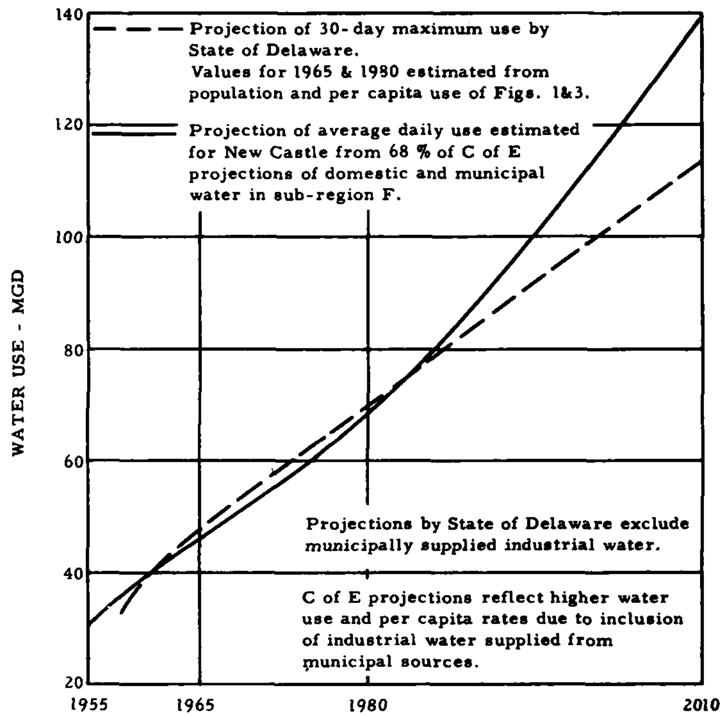


Fig. 2 WATER CONSUMPTION

All data apply to New Castle Co. only
See para. 45.

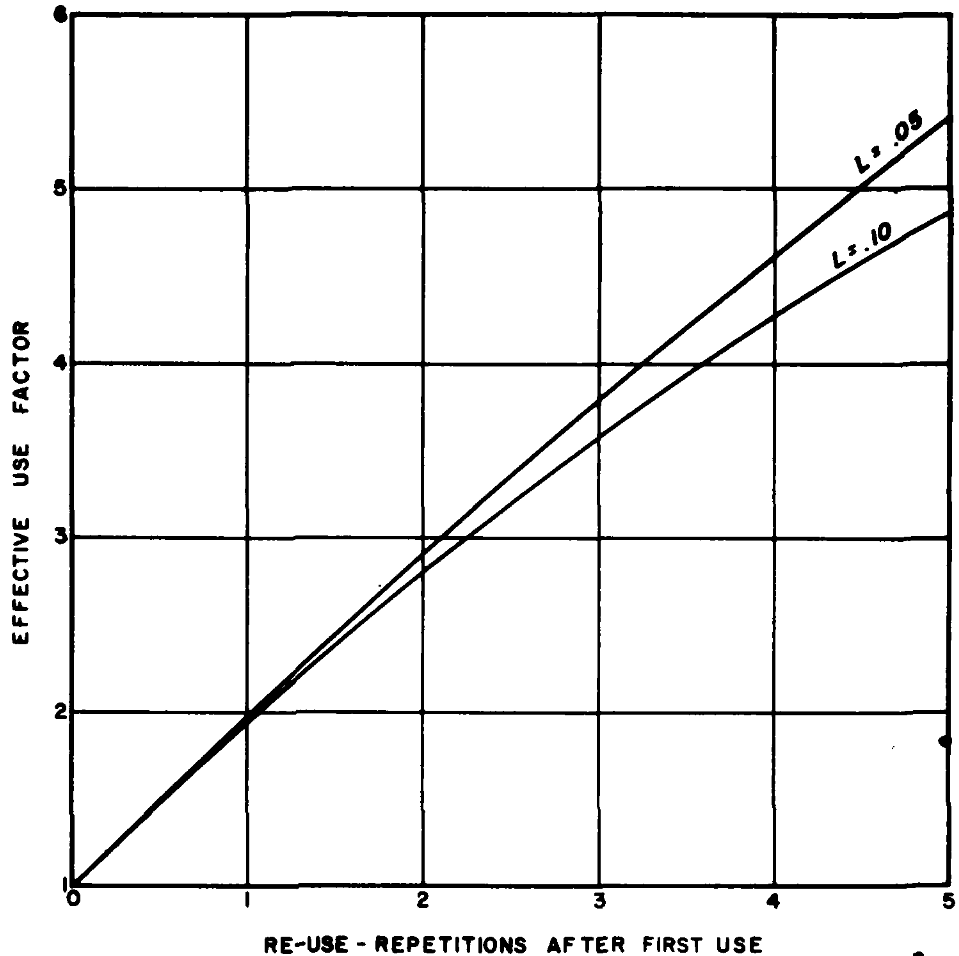
REVIEW REPORT
DELAWARE RIVER BASIN

GROSS WATER NEEDS
NEW CASTLE CO., DEL.
DOMESTIC AND MUNICIPAL USE

In 1 Sheet | Scales as Shown
Corps of Engineers | Philadelphia District
Philadelphia, Pa. | 10 December 1959

Drawer No. 228 | File No. 29146

PLATE 13



NOTE: Relation based on effective use $1+\int_0^n (1-L)^n dn = \left.\frac{(1-L)^n}{\log_e(1-L)}\right]_0^n$

Where L = consumptive loss as a fraction of total use.

For L = .05 effective use $20.49 - \frac{(.95)^n}{.0513}$

n = no. of repetitions of use after first use.

For L = .10 effective use $10.49 - \frac{(.90)^n}{.1054}$

REVIEW REPORT
DELAWARE RIVER BASIN

RELATION OF EFFECTIVE
USE TO RE-USE

In 1 Sheet Scales as Shown
Corps of Engineers Phila. Dist.
Philadelphia, Pa. 28 Sept. 1959

Drawer No. 228 File No. 29071

CORPS OF ENGINEERS

U.S. ARMY

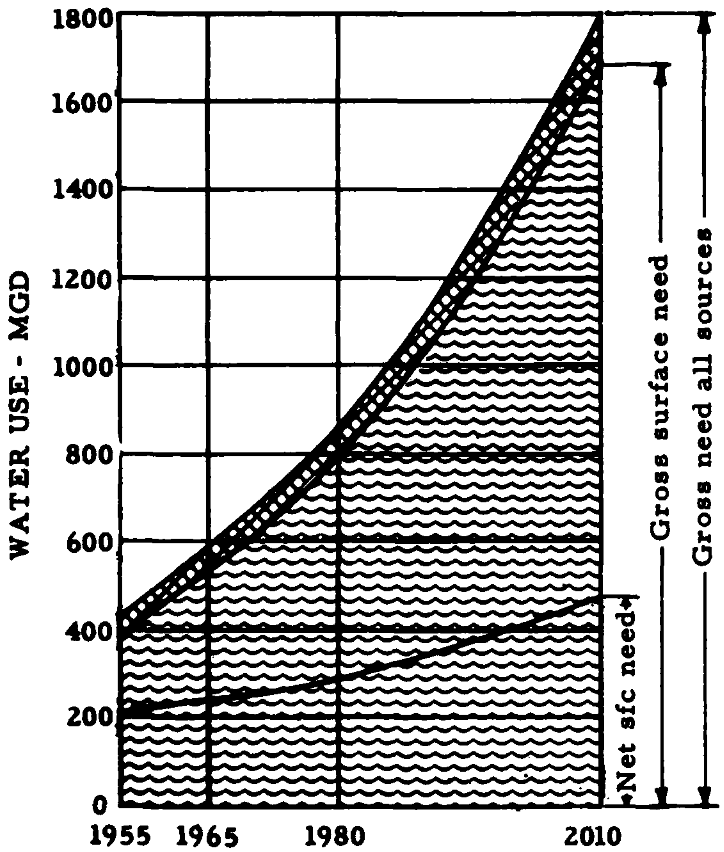


Fig.1. GROSS & NET WATER NEEDS

Ground Surface

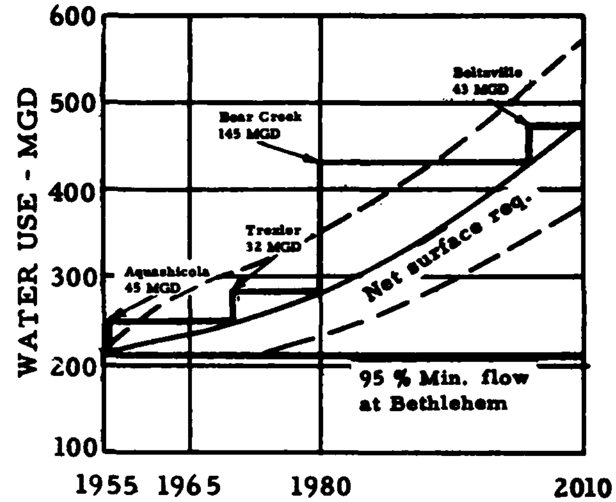


Fig. 2. STORAGE POTENTIALS

— — 20 % error limits

REVIEW REPORT

DELAWARE RIVER BASIN

GROSS & NET WATER NEEDS AND STORAGE POTENTIALS LEHIGH AREA

In 1 Sheet
Corps of Engineers
Philadelphia, Pa.

Scale as Shown
Philadelphia District
23 Oct. 19[illegible]

Drawer No. 228

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CORPS OF ENGINEERS | U.S. ARMY

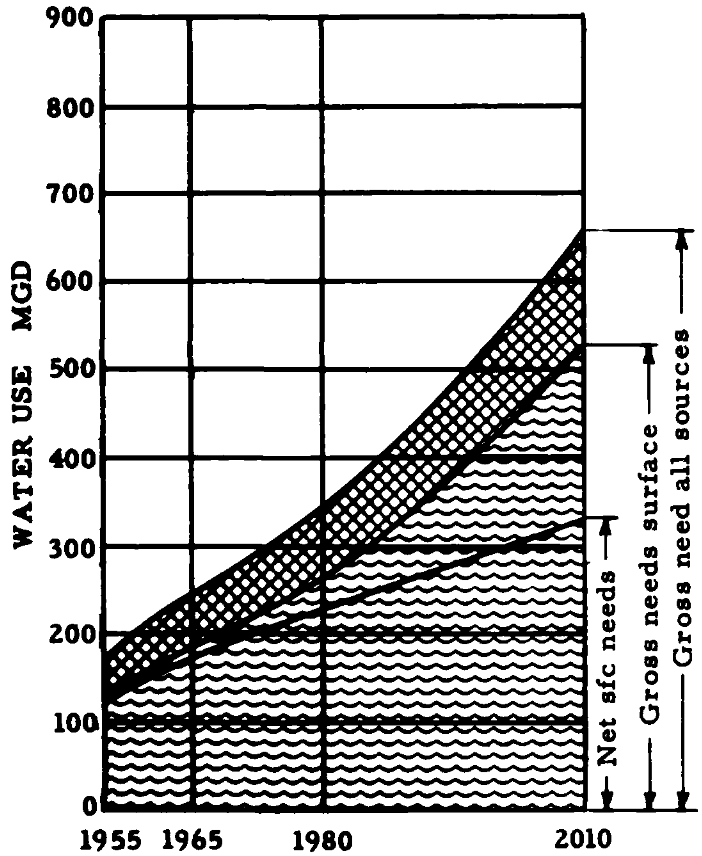

Fig.1. GROSS & NET WATER NEEDS

Ground | Surface

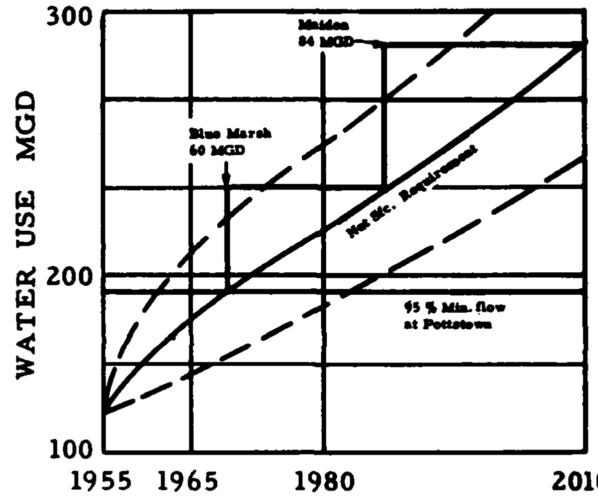

Fig. 2. STORAGE POTENTALS

— — 20 % error limits

REVIEW REPORT

DELAWARE RIVER BASIN

GROSS & NET WATER NEEDS
AND STORAGE POTENTIALS
UPPER SCHUYLKILL AREA

In 1 Sheet | Scale - as Shown
Corps of Engineers | Philadelphia District
Philadelphia, Pa. | 23 Oct. 19[illegible]

Drawer No. 228 | File No. 29148

PLATE 16

CORPS OF ENGINEERS U.S. ARMY

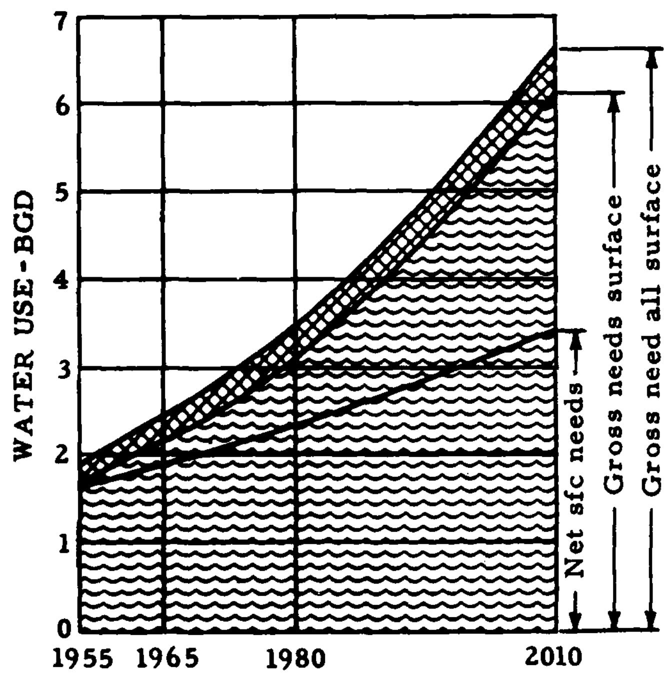

Fig. 1. GROSS AND NET WATER NEEDS

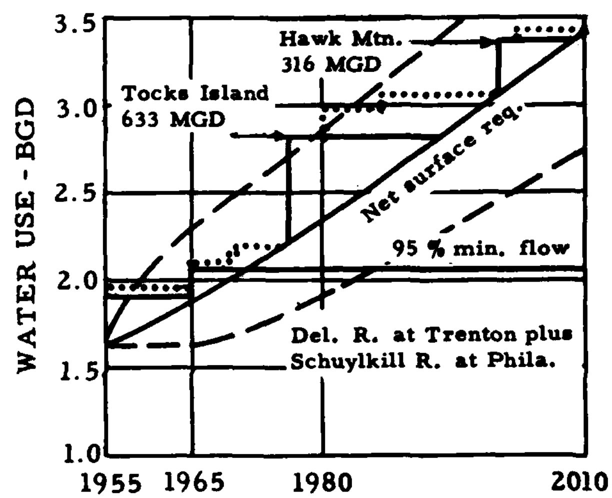

Fig. 2. STORAGE POTENTIALS

Dotted lines indicate augmentation of flow provided by water supply reservoirs in Lehigh & Upper Schuylkill areas.

See Plates 12, & 13.

— — 20 % error limits

Ground Surface

REVIEW REPORT

DELAWARE RIVER BASIN

GROSS & NET WATER NEEDS

AND STORAGE POTENTIALS

TRENTON-PHILADELPHIA AREA

In 1 Sheet	Scale as Shown
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Philadelphia, Pa.	23 Oct. 1959
Drawer No. 228	File No. 29149

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U.S. ARMY

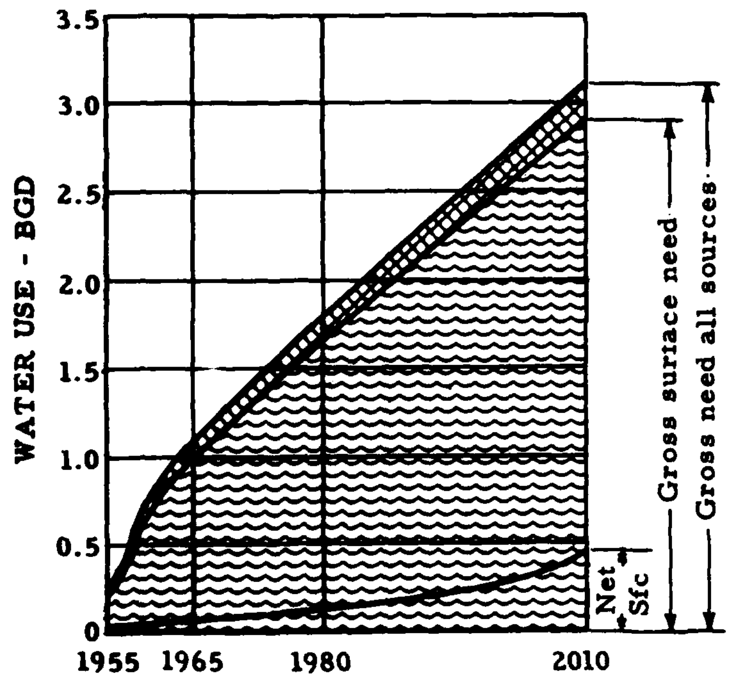

Fig. 1. GROSS & NET WATER NEEDS

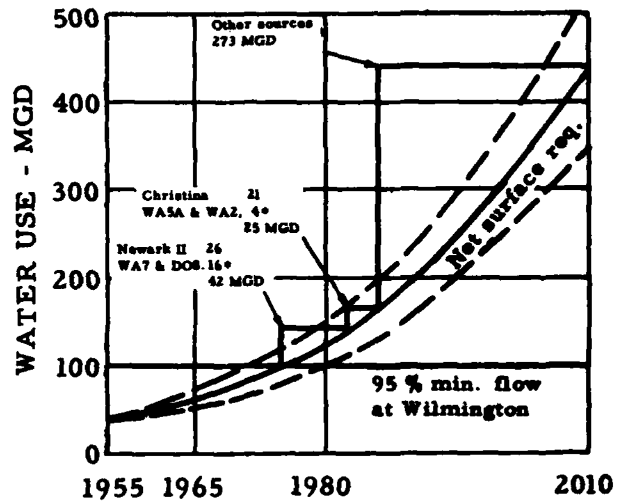

Fig. 2. STORAGE POTENTIALS

Other sources are diversion from Delaware R., Barrier Dam, or diversion from other sources outside the basin.

— — 20 % error limits

Ground

Surface

* In recommended water resources development plan of Brandywine Creek Basin, Commonwealth of Pennsylvania, Dec. 1958.

REVIEW REPORT

DELAWARE RIVER BASIN

GROSS AND NET WATER NEEDS AND STORAGE POTENTIALS WILMINGTON AREA

In 1 Sheet
Corps of Engineers
Philadelphia, Pa.

Scale as Shown
Philadelphia District
23 Oct. 1959

Drawer No. 228

File No.29150

REPORT ON THE

COMPREHENSIVE SURVEY

OF THE

WATER RESOURCES

OF THE

DELAWARE RIVER BASIN

APPENDIX Q

FORMATION OF THE PLAN OF DEVELOPMENT

PREPARED BY

U. S. ARMY ENGINEER DISTRICT, PHILADELPHIA
CORPS OF ENGINEERS
PHILADELPHIA, PA.
JUNE 1960

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FORMATION OF THE PLAN OF DEVELOPMENT

I INTRODUCTION

1. The formation of an optimum plan for the comprehensive long-range development of the water resources within any given geographic confines is an undertaking for which there is no strict and formalized procedural structure at the present stage in the art of water resources planning. It requires the assembly of a great amount of data on the physical features and economic development and activities of the area in question, the establishment of clarifying goals and assumptions, the sage application of tried and new procedures, and finally, the weighing and measuring of the findings to identify those development features most favorable or conducive to the given objective. This appendix explains the bases and techniques used to form the optimum plan for the development of the water resources of the Delaware River basin. The extent and nature of the planning concepts and the confines and parameters involved are described. The problems associated with the basin's water resources, expressed in terms of the needs for the products that could be developed from these resources, are defined and the established goals for satisfying the needs are given. This appendix presents basic data and appraisals of the measures and facilities considered in the solution of the problems; explains the procedures used; and, finally, presents an integrated plan of development.

II PLANNING ENVIRONMENTS

2. GENERAL CATEGORIES. The primary conditions and influences affecting the forming of the plan were (a) the objectives to be met, (b) the physical characteristics of the basin, (c) the times involved and the areas to be served, (d) the social and economic factors, (e) the data available and (f) the procedures employed. These are discussed below.

3. OBJECTIVES TO BE MET. The first objective to be met required that the planning studies undertaken for this report be comprehensive in both breadth and depth. The nature and extent of the planning studies were in accord with the directives of the Congress as expressed in resolutions of the Committees on Public Works of the United States Senate and House of Representatives. Of the seven resolutions 1/ pertaining to this survey, five of them directed generally that prior reports be reviewed to determine whether any improvements for flood control and allied purposes are advisable at this time. Some of these resolutions applied to the entire Delaware River basin and others applied to specific segments of the basin. The complexity of the investigations was altered materially by a resolution of the Committee on Public Works of the U.S. Senate adopted on 20 February 1956. That resolution directed the Chief of Engineers to review prior reports on the Delaware "in connection with the pending comprehensive survey of said stream with a view to determining the feasibility of construction and operation of a reservoir on the main stem of the Delaware River above Delaware Water Gap near Wallpack Bend or Tocks Island, on a cooperative basis by the United States and the Commonwealth of Pennsylvania and the State of New Jersey, as an integral unit of a comprehensive plan for the control and utilization of the water resources of the Delaware River in the interest of flood control, navigation, water supply, stream pollution abatement, recreation, control of the movement of salt water, electric power, and other purposes." The complex, comprehensive nature of the studies directed by the Congress was further emphasized by the resolution of the Committee on Public Works of the U. S. Senate, adopted 28 April 1958, which directed a review of prior reports on the Delaware River, "in conjunction with the pending comprehensive survey of said stream, with a review to determining the feasibility of construction of a barrier in the Delaware estuary, such study to consider the economic and physical

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1/ Each of the resolutions is quoted in full in Appendix A, "History of the Investigation" prepared by the U. S. Army Engineer District, Philadelphia.

effects of such a structure, the costs and potential benefits of the structure, and the economic and physical relationship of such a structure to other works of improvement now being planned for the Delaware River Basin."

4. While a number of the authorizations directed investigations related to particular project purposes, the Congress, in the Senate Resolution of 20 February 1956 directed that the plan for the control and utilization of the water resources of the Delaware River Basin encompass a multiplicity of stated purposes wherein it is implied that no single purpose is to hold dominance over any other purpose. Thus the Congress prescribed the comprehensive nature and extent of the planning studies to be undertaken in formulating the plan delineated herein. In complying with such directive the regional significance of the Delaware River as a source of water to meet the needs imposed by human use and activities imposed broad and complex requirements on the planning assignment. For example, there was imposed a responsibility to develop a plan for control and utilization of the water resources of the Delaware River Basin which would reflect the impact of water use on the region's social and economic well-being. Also, it must be a plan within which each indicated use of water would find its proper position, in the broad constantly expanding field of progressive development, consistent with the relative values of other forms of development needed to sustain and nourish the growth of the region. Finally, to be comprehensive in depth the plan must encompass (1) all classes of water control from simple land management measures to major multi-purpose impoundments and (2) all water uses from those required for primary plant life to those attending the complex activities of huge modern communities. It was understood at the outset that this comprehensive approach to development of the water resources of the Delaware River Basin would be undertaken within the general constraints set by existing laws and policies of government, and would need to reflect the controls and responsibilities of the various levels of government and established financing procedures.

5. The second objective to be met dealt with the utilization of existing capabilities in water resources planning. To achieve a comprehensive plan of regional scope for the beneficial control and utilization of the water of the basin it was apparent that the plan would have to reflect the views and interests of all water users as these are represented by public agencies at all levels of government and by private agencies where such agencies reflect the public interest in resources management. Furthermore, it was necessary that the optimum plan reflect the effects of going programs, in various stages of completion, by the Federal and non-Federal agencies concerned. Accordingly a cooperative approach to planning was adopted whereby the proficiencies of these agencies

were employed. Assignments to cooperating agencies, funding arrangements, and coordination of the planning studies were accomplished by the District Engineer, U. S. Army Engineer District, Philadelphia, acting as overall coordinator for the cooperative planning effort. Details of these arrangements are presented in Appendix A. The adopted cooperative arrangements provided for coordination at two working levels; a technical level and an administrative level. For example, the task of developing a recreational plan for the study area was assigned to National Park Service. This Service coordinated the preparation of such a plan at technical level among recreation agencies at all levels of government. The result of these technical studies presented in the form of recommendations, estimates and appraisals by the National Park Service, was then distributed by the Corps of Engineers for review and comment by all interests at the level of the Coordinating Committee composed of administrative personnel. Similar arrangements attended the preparation of other appendices to the report.

6. PHYSICAL CHARACTERISTICS. Probably the most exacting influences affecting the forming of the plan of development for the Delaware River basin are those that come under the category of "physical characteristics". Under this broad category are found such primary factors as the actual surface and sub-surface geography of the area within the basin boundaries; the quantity, quality and areal distribution of the basin's water resources; and the type, intensity and dispersal of man's activities in the basin, including the existing and authorized programs pertaining thereto. There is inherent among these factors a number of strong interdependencies that enhance their individual influences on project formulation.

7. Upper Basin. The basin is traversed and roughly bisected by the Kittatinny-Blue Mountain ridge that extends in a northeast-southwest direction near the midpoint of its northsouth axis. To the north of this ridge the basin area is rough and hilly with narrow stream valleys. This region is featured by extensive timbered areas with only modest extents of cultured areas. The inhabitants of this region are concentrated in a large number of relatively small communities. The economy of this upper area is supported primarily by the recreation industry. It would seem that this upper area would be ideal for the development of water resources projects. However, the rough, hilly nature of the area militates against this development potential by having forced extensive highway and railroad systems and numerous small communities to locate within the narrow confines of the flood plains. Furthermore, potential sites for major control works have been preempted by projects of the New York City Board of Water Supply on East Branch and West Branch of Delaware River and on Neversink River, by power projects on Wallenpaupack Creek and Mongaup River and by Federal flood con-

trol projects in the Lackawaxen River basin and the upper Lehigh River basin. Also, potential sites for major control projects in the Beaverkill basin are inaccessible because of their adverse effects on fish-life in that stream. The surface and ground-water resources of the area are plentiful and well distributed. The quality of these water resources is exceptionally good except in the Upper Lehigh River basin where mine drainage in some of the tributaries has an adverse effect on the water quality 2/.

8. Lower Basin. The basin area to the south of the Kittatiny-Blue Mountain ridge is rolling with the relief diminishing into the flat coastal plains in extreme southern portions of the basin. The population is densely concentrated and the industrial activities are intensive in this area, particularly in the vicinity of the Trenton-Philadelphia-Chester-Wilmington axis. The valleys in the lower portions of the basin are relatively narrow and, for the most part, cluttered with railroads, highways, urban settlements, and extensive industrial communities. The potentials for developing major water impoundments in relatively unused tributary reaches are limited and many of those that are now available are in imminent dangerof being engulfed by spreading suburban developments. In this portion of the basin potential major impoundment sites have been preempted by water supply projects on Maiden Creek, Perkiomen Creek and Crum Creek. Also, watershed programs have been initiated for the Perkiomen, Wissahickon, and Brandywine basins. The Delaware River below Chester, Pennsylvania, is brackish and is used extensively as a source of cooling water. Above Chester, the Delaware River and its tributaries could provide ample fresh water if major impoundments and other facilities to permit their full exploitation were feasible. The ground-water resources are ample in the New Jersey portion of this region and in some areas of the Pennsylvania and Delaware portions. However, in these latter portions of the lower basin some local areas, such as that in the vicinity of Lansdale, Pennsylvania, suffer critical shortages of ground water. The qualities of both surface and ground waters in the portion of the basin south of the ridge vary in a wide range but, with proper safeguards, are acceptable for present uses. However, expanding urbanization may adversely affect future surface water qualities in some areas. The quality of Schuylkill River flows has been greatly improved in recent years by the construction of Federally sponsored desilting basins built and financed by the Commonwealth of Pennsylvania and now being maintained and operated by the Commonwealth. Four active

2/ Appendix C, "Water Use and Stream Quality", prepared by the U. S. Public Health Service, U. S. Department of Health, Education and Welfare.

river desilting basins are located at Tamaqua, Auburn, Kernsville and Felix, Pennsylvania. Of these, the Felix project was constructed from an old existing dam. Hydraulic dredges and associated equipment are maintained by the Commonwealth at each of these projects.

9. Effects of Physical Characteristics. The present and anticipated future use of the land and water resources of the basin foretell difficulties in controlling a substantial portion of the surface water resources with reasonable investments. The current planning environment with regard to the physical characteristics of the basin was one of optimum exploitation of remaining potentials compatible with and complimentary to the present and planned investments of public and private capital and goods in the basin's resources.

10. TIMES AND AREAS. Time was recognized at the outset as a major factor in conditioning the character of the present study. To meet the requirements of a comprehensive study of regional scope it was apparent that something more than an evaluation of the problem under current conditions of demand and supply was required. Consideration had to be given to interpretation of the total problem in terms of balancing the water product needs of a growing population and associated economic trends by means of a program of water development which would provide for the satisfaction of such needs over a given period of growth. Accordingly, projections of population, personal income and industrial activity are contained in the Economic Base Survey 3/. Because of its use as a basis for projections of future water use and control problems, a principal requirement upon the Economic Base Survey was that it reflect the probable long range trend with intermediate projections properly spaced in time to minimize the effects of short term variations. The projections in that Survey were made for the basin proper and subregions thereof, as well as for a larger water service area which extends beyond the basin boundary as described below. A period of 50 years was designated at an early stage of the investigations for all projections with intermediate points of projection at 1965 and 1980 and terminal date at year 2010. Because of basic data available, the projection period is actually from year 1955 to year 2010. However, cost data used for planning purposes reflect early 1959 conditions.

3/ Appendix B, "Economic Base Survey", prepared by the Office of Business Economics, Department of Commerce.

11. An equally sensitive factor in conditioning the character of the study was the geographic area involved. In this case the influence generated from two basic sources, namely, the dimensions of the area of use of the basin's water resources and the geographic distribution of the problems associated with and the products derived from water resources. The first of these - the dimensions of the area of use - would normally be defined as that area within the basin boundary but the area of use for water resources of the Delaware River basin was defined, to a large extent, by the present usage of the basin's water including authorized diversions from the basin. The diversions extended the dimension of the water use area to regions outside the basin boundary and, particularly, to the standard and expanded New York City metropolitan areas. Other periphery regions outside the basin in New Jersey and Delaware were considered to be in the water service area because of their apparent eventual dependency on the Delaware River basin as a source of fresh surface water supplies. The overall water service area thus defined is shown on plate Q-1.

12. For some products of development of the basin's water resources, the area of current and potential use may be more or less distinct than the service area delineated on plate Q-1 would indicate. For example, the area of use of land treatment measures for control of the headwaters is limited to the immediate locale of the measures and to somewhat less limited areas of ground-water influences emanating from the vicinity of the measures. On the other hand, the service or market areas for such products as domestic and industrial water supplies and hydroelectric power that can be conveyed to the ultimate consumer is limited only by the practical aspects of the distribution systems. Also, for such products as recreation where mobile ultimate consumers come to the point of production the extent of the service area must be defined by the practical application of empirical formulae to such markets.

13. The geographic distribution of the problems and products of water resources wields a somewhat different areal influence. For example, water supply developments in the Schuylkill River basin afford poor potentials for alleviating low flow problems in the Lehigh River basin. Similarly, flood control storage in the upper reaches of the Delaware River can do little to alleviate flood problems in the Lehigh and Schuylkill basins. This type of influence requires that the overall water service areas be reduced to a series of composite problem areas following roughly the natural geographic subregions of the service area. Within the basin boundary the major tributaries and reaches of the Delaware River logically define problem or market areas that can be readily related to the geographic distribution of measures to satisfy their needs.

14. SOCIAL AND ECONOMIC FACTORS. The ultimate objective of any plan of water development is to serve the people concerned. In this case the population of the various subregions 3/ of the water service area, delineated on plate Q-1, are considered as constituting the major market for goods and services produced by the proposed plan for development of the water resources of the Delaware River basin. Problems of analysis arise, however, because a substantial part of the market for goods and services expected to be produced by development of the water resources of the basin resides outside the drainage area in which actual physical improvements are proposed and improvements must be planned with full recognition of the potentialities for meeting the water needs of the people of major portions of the service area from alternate sources which lie outside the area of the Delaware River basin. Fortunately, these problems tend to resolve themselves because of peculiarities inherent in each segment of the market for water produced goods and services; that is, while the above defined market and geographic area constitutes the basic study area, each market for such products as recreation, hydropower, and water supply exhibits its own individual characteristics.

15. The region associated with the water resources of the Delaware River basin constitutes one of the most important regional economic areas of the nation. While embracing less than one percent of the total land area of the United States, this region accounts for more than 13% of its population, provides about 14% of the nation's labor force and produces over 16% of the country's total personal income; the latter, on a per capita basis, being one-fourth higher than that for the nation. Within the basin itself are found major segments of our nation's steel, chemical, petroleum and paper and board capacity. Indeed, the impact and influence resulting from the utilization of the basin's water resources is felt not only within the region but by the nation as a whole. The market for the basin's water resources products arises from the fact that substantial portions of the 21 million people residing in the area and the myriad of industrial and commercial establishments located in the basin presently require that about 1,500 billion gallons of water each year be withdrawn from the available supplies to satisfy their serveral needs. Still other markets for water resource products stem from the use of the streams and tributaries to provide the movement of about 100 million tons of goods into and out of the lower section of the basin as well as providing many of the recreational outlets for the over 3-1/2 million visitor-days recorded for the basin. Lack of control of extreme variations in the water resource creates a major market or need for the reduction of flood damages at one extreme and a major market for increased supplies of water at the other extreme as dramatically illustrated by the August 1955 flood that resulted in over $100 million of damage and by the drought of the 1950's in which severe water shortages occurred. These and other water resources goods and services will

3/ Ibid

be required in ever increasing amounts to satisfy the needs of the area's growing population and its expanding industrial activities. Within this social and economic environment, characterized by a large population, a higher-than-average personal income, and a vigorous industrial development, it was essential in planning that the plan of development be attuned in all phases of formulation to the contribution that water resources make to the region's social and economic well-being.

16. PROCEDURES AND DATA. It became apparent early in the planning effort that major problems relating to the uniformity of appraisals and measurements and to the adaption, modification and development of acceptable procedures would have to be resolved. The provision of each product of water resources development was established initially in these analyses as a coequal project purpose rather than as an incremental or collateral function of a basically unilateral project or program. The procedures for forming multiple-purpose programs required that each purpose be entered into the analyses on a basis of justification comparable among all purposes, quantitatively defined in terms of market, costs and benefits.

17. Procedures. Despite the difficulties encountered in uniform and coequal appraisals of project purposes, the experience gained here indicates that the comprehensive multiple-purpose approach as applied to this planning effort, provides a more valid argument for providing the proper and equitable distribution of emphasis among water use purposes than would have been the case had neither regional significance or coequal treatment of water use purposes been employed. Later in this appendix are described the steps in planning and the procedures and methods utilized as well as explanations of the bases for decision making employed in arriving at the recommended plan of improvement.

18. Comparable Measurements of Various Goods and Services. In planning procedures based on the concept of coequal purposes the various functions must be quantitatively defined in terms of costs and product values. To be useful in sound planning analyses these definitions must be in terms of similar units of measurement for each of the project purposes. In the case of costs, it would appear that comparable measurements for flood control, water supply, hydroelectric power and other functions could be assured by the uniform use of, say, the 1959 price level. 3/ While the use of a uniform price level is a basic necessity, there still remain some unresolved cost problems. These problems arise from the differences in costs of goods and services at the point of production and the cost of these same goods and services at the point of their effectiveness or ultimate use. In other words, various distribution or transportation costs, in some cases to unknown future points

3/ Ibid

of use, may be involved. In order to recognize the differences in such costs attendant upon use of alternative solutions to specific water resource problems, studies to define the plan of development were based on appraisals of costs and benefits at the point of production. However, at site hydroelectric power values based on fuel-electric costs were adjusted in recognition of differences in costs of transmission.

19. The values to be assigned to the water resources goods and services utilizing comparable units of measurement (as a base for defining the plan of development) also posed some problems. In this case, a complete appraisal of the effects of the water resources development on the economy of the region would require that the value of the goods and services be based on the net gains to the ultimate consumer accruing from their use. Land treatment measures to control and utilize water resources at the furthermost upstream levels are unique and inextricable portions of a broad resources conservation program which are difficult to evaluate. Practice has established procedures whereby the values of flood control have been based on estimates of flood damages eliminated and hydroelectric power values have been based on the estimated worth of the installed capacity and the estimated value of the fossil fuel required to produce equivalent amounts of electrical energy. In a sense, the values used in these cases are the costs of alternative measures or facilities to produce equivalent amounts of goods and services. The critical position occupied by water supply, <u>per se</u>, in the regional economy assures that its minimum value to the region is the cost of the least expensive alternative measures for satisfying the water needs likely to be undertaken in the absence of the projects under consideration. The use of alternative facilities as a measure of the value of recreation as it relates to water resources is neither direct nor simple because of the wide range of alternative recreational activities available and the dearth of cost data for many of these alternatives. In spite of the limitations involved, both in the appraisals and their use for comprehensive planning purposes, the cost of alternative measures or facilities, or generalized estimates based on such costs, were utilized as necessary to measure the values of the goods and services to be produced by the development of the basin's water resources. The details of those appraisals and their application in the planning procedures are discussed at appropriate points later in this appendix.

20. <u>Data</u>. A relatively large number of potential projects and improvement measures were considered in arriving at a development program for the basin. The task of analyzing these many potentials for improvements was simplified by varying the extent of basic data assembly and the scope of studies with the complexity of the project and the stage of project investigation. Those were

varied progressively from minimum details in the earliest appraisals to the greatest practical level of detail in the final stages of the studies. In the early stages of the investigations data on the physical and geographic dimensions of the projects were obtained from prior studies and maps available from the U. S. Geological Survey and other sources. Cost estimates were based on preliminary layouts and simplified or reconnaissance type of estimating procedures. As the planning proceeded, step by step, basic data from field surveys, subsurface investigations, construction materials surveys, and real estate appraisals in the field were added progressively; project layouts and structural designs were revised as added field data and project planning studies indicated, and cost estimates were refined with regard to quantities and firmness of unit prices. Similar progressive appraisals were made of the goods and services produced by the projects and the values thereof. Sources of data in these instances were those cooperating agencies in whose field of primary interests the evaluations would normally fall. For example, hydroelectric power appraisals were from studies of the Corps of Engineers, utilizing estimates of capacity and energy values prepared by the Federal Power Commission, recreation appraisals from the studies by National Park Service and fish and wildlife appraisals from the Fish and Wildlife Service. The actual nature and sources of estimates of costs and worth of goods and services used at various stages in the studies are reported at appropriate places later in this appendix.

21. SUMMARY. It has been shown that studies to form the optimum plan of development for the water resources of the Delaware River basin were made under environments peculiar to the nature and scope of the planning effort and to the area under consideration. The requirements that the planning be on a comprehensive basis both with regard to the problems and products and with regard to cooperative study arrangements created unique conditions. The influences of physical characteristics encountered in all water resources planning efforts were felt to varying degrees in the formulation studies. Time, areal, social and economic factors, exerted their influences in a distinct and interrelated manner, that reflected the mature nature of the area involved. Finally, all of the conditions and influences attending the studies combined to place unusual demands on the procedures and data used to arrive at the final definition of the plan of development. With these environments as background, the definitions, discussions and detailed planning procedures presented in the following sections of this appendix will take an added level of significance.

III PROCEDURE FOR DEFINING THE PLAN OF DEVELOPMENT

22. GENERAL PROCEDURE. The procedure for defining the optimum plan for development of the water resources of the basin within the above described environments comprised three broad planning steps. Briefly, these steps were:

a. The definition of present and future water control problems expressed in terms of the nature and dimensions of the needs for the various goods and services of water resources development;

b. The inventory and appraisal of the practical facilities and measures within the basin that could be used to solve the water control problem (or satisfy the market) defined in the step above;

c. The use of successive evaluations of the costs and worth of providing the needed goods and services by alternative developments to arrive at a plan of development which would assure a maximization of net return while meeting, with minimum investments in funds and developable measures, the need for a multiplicity of products associated with water control.

These three steps and the considerations involved are discussed in the paragraphs below.

23. WATER CONTROL PROBLEMS. The nature and extent of the water control problems were expressed, for planning purposes, in terms of the needs for the various goods and services to be produced by the control of the uneven stream flows of the basin. These needs are related to the people and the economic activities that are directly or indirectly dependent on the basin's water resources. Overall planning procedures consistent with this dependency had to take into account the need for a balanced production of the various goods and services. While it can be demonstrated that development of the water resources for only one or two purposes may result in very favorably justified projects, any resultant widespread preclusion of use of water for other important purposes would be inconsistent with optimum utilization of these resources. Accordingly, design of a balanaced plan of water resources development consistent with the needs of the Delaware River basin and service area was adopted as a basic planning goal.

24. The analysis of the needs for the products of water control involved separate studies of future gross and net water demands; damages from flooding; electric power market; requirements for hunting, fishing and recreation opportunities; agriculture; water quality; navigation; and an economic base survey.

The results of these studies are reported in appendices to this report and are discussed in later sections of this appendix.

25. <u>FACILITIES AND MEASURES TO RESOLVE WATER CONTROL PROBLEMS</u>. The needs of the basin and water service area for the various water resource products can be satisfied wholly or in part by development measures to impound and control the surface waters of the basin. From an analysis of product demand as related to the needs of the economy, it was possible to identify the basic requirements to be met and the development measures required to produce them. This identification required a general knowledge of all productive measures in the basin that appeared susceptible to practical development. The process of identifying these production measures called for basic studies in hydrology, geology, stream quality, land treatment, upstream reservoirs, major control structures, local flood protection works, and a salt water barrier.

26. The extent and nature of the production measures to be included in the optimum plan of development had to be based on sound economic analyses. Wherever monetary values were assigned reflecting the communities' evaluation of water resource products against each other and among other types of products, there was implied to exist a private market in which the interactions of consumers and producers determine the quantities and prices of the goods and services to be produced. It was implied, also, that for water resources products it is possible to achieve complete integration of the recognized product interdependencies. In this case the principles of maximization would be satisfied when the development is undertaken in such manner that the differential between development gains and costs is at a maximum. The optimum development for the desired balance of products would be achieved in this case since it has been assumed that the communities' relative evaluation of goods and services are reflected in the choice of project purposes that yield the greatest maximum of benefits over costs.

27. In the present survey (aside from the constraint of limited productive resources) the absence of a private market as basis for assigning monetary values to the water derivatives reflecting the communities' evaluation of such products, prevented the definition of the plan of development in the ideal manner described in the paragraph above. However, as expressed above, the analysis of product demand as related to the needs of the economy, provided a basis for identifying the basic requirements that may be met by water control measures. The elements and dimensions of the optimum plan could then be defined by application of maximization procedures wherein the productive resources were allocated in such manner that no other allocation would achieve the desired output with lesser investment in productive resources.

28. It was apparent that because of economic constraints attending the planning procedures the optimum plan of productive measures would be incapable of completely satisfying all the water resources needs of the basin and water service area. If the satisfaction of all or portions of these residual unsatisfied needs is to be undertaken it appears that supplemental programs to modify net water uses by recycling and increased repetitive use, to control use of the flood plains, to improve the quality of the surface waters, and to control the use of ground-water resources offer the greatest potentials for accomplishing this task in an economical manner. These supplemental programs are discussed later in this appendix.

29. EVALUATIONS AND PROCEDURES FOR ESTABLISHING THE PLAN OF DEVELOPMENT. The third and final step in the general planning procedures dealt with the evaluations used and procedures followed in establishing the optimum plan of development of the basin's water resources. This planning step was contrived with a view to adhering, to the greatest practical extent, to the principle of maximized net returns. As applied here this principle required that detailed procedures to be followed in forming the plan be such as to assure a balanced program of water resource development to satisfy the economic and social needs with a maximized output from minimum investments in productive resources.

30. Available Methods. Before adopting a set of evaluations and procedures to be used in this investigation to establish the basic plan of development, two broad methological approaches were studied and appraised. These two methods were the mathematical model and the method of sequential appraisals. The findings with regard to their application are given below for each method.

a. Mathematical Model. Formulation of a formal mathematical model that would directly lead to a solution fully consistent with the planning principles adopted for this survey was studied generally for its possible application here. The basic premise of this method assumes that it is possible to construct a direct mathematical correlation among the pertinent variables to be considered in forming the development program. This method can be readily applied in simple cases involving perhaps one production measure serving a limited number of complementary functions. Also, it was found that this method might be useful in certain initial screenings made as individual features of the overall evaluations. However, it was not possible to develop a mathematical model for complete solution of all or any substantial part of the planning job for the Delaware River basin.

b. Sequential Appraisals. Closely related to the mathematical model procedure is that method involving a series of repetitive determinations by which it is possible through sequential testing of a project or series of projects to arrive at a reasonable solution, consistent with the adopted planning principles. This method is specially suited to that situation described above where the planning must adhere to the principle of maximized net benefits. The procedure to be followed in this case is generally expressed in a mathematical formula involving differential calculus and the number of separate determinations may be extremely burdensome when the procedure is applied without simplifications to the complex analysis of the water resources of the entire river basin.

31. Adopted Evaluation Method. The evaluation method adopted in this survey for deriving the composition and dimensions of the optimum plan of development was essentially a simplified adaptation of the sequential appraisal method referred to above. The adopted method involved a set of successive determinations by discrete screenings to establish the composition of an optimum plan of basic productive elements. Then, detailed appraisals were made to establish the optimum dimensions of each element. The details of this method are described in a later section of this appendix.

IV NEEDS FOR PRODUCTS OF WATER RESOURCES DEVELOPMENT

32. GENERAL BASES FOR QUANTITATIVE DEFINITION OF NEEDS. The preceding sections of this appendix have set forth the environments under which the plan of development was formed and the overall procedure for defining the plan of development. The first step in this latter procedure was the quantitative definition of the needs or dimensions of the markets for the various products of water resources development. This definition required examination of the past, present and future economic development of the region to relate water resource development needs to economic growth. With this background, the dimensions and areal distribution of the needs for the various water resources products over time could be fixed with some degree of confidence. This section presents the nature and quantitative definition of the existing markets for the water resources goods and services.

33. ECONOMIC DEVELOPMENT OF REGION. To chart the past and future economic growth of the Delaware River service area and its subregions, historical and projected levels of population, employment and personal income were prepared by the Office of Business Economics. 3/ In describing the economy of this region, personal income was adopted as the most comprehensive measure of economic activity which can be prepared on a geographic basis. Through careful analysis of personal income in terms of the historical shifts in sources of personal income both by industry and by type, it was possible to identify the dominant economic factors that have contributed to the past and present levels of economic development and those that reasonably may be expected to shape the pattern of future development.

34. Economic Growth. By 1955, (the last year for which employment and population figures are available on an area basis), the twenty-one and a half million residents of the Delaware River service area, providing a labor force of nine million people received $51 billion of personal income. By 1957, aggregate income had increased to nearly $58 billion, an advance of almost $7 billion in two years. On a per capita basis this amounted to $2,600, one-fourth higher than that for the nation as a whole. While the service area's total personal income grew at an annual rate of 2% compared to the national rate of about 3% between 1929 and 1957, per capita personal income for the area as a whole has consistently been well above the national average, indicating the high level of economic well-being that has been attained in this region. Based essentially on an extension of past differentials in rates of growth between the region and the nation, it is anticipated that personal income for the area by 2010 will have quadrupled and real per capita personal income will be more than twice its present level.

3/ Ibid

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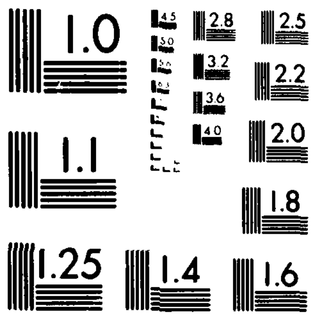

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35. The projected growth rate of personal income for the service area is somewhat higher than that of the past 25 years. From 1929 to 1957 total income in the region grew at an average annual rate of slightly more than 2% while the average annual rate embodied in the projection for the next fifty years is over 2-1/2%. The factors involved in the assumed increase of the growth rate in personal income can be seen in an analysis of the income structure of the service area. The differential in personal income growth for the service area and the nation between 1929 and 1957 has been due partly to this region's greater dependence on those income sources which have advanced at a slower rate than the total rate of advance for the nation. However, by 1957 the service area's economy apparently had become more analogous to that of the nation in eight out of ten major industrial sources of income. The region's relative decline in income position since 1929 also reflects the fact that this area had achieved a large degree of economic maturity by 1929. Of singular importance in the projection of personal income has been the recent trend in the rise of manufacturing earnings as an income source and the decrease of the importance of property income between 1929 and 1957. Furthermore, since 1929 factory earnings have increased more than three times as compared with a rise of one and one-half times in non-manufacturing income. All evidence indicates that manufacturing activity is a force tending to quicken the pace of future economic growth in the service area. Based on these analyses it has been indicated in the Economic Base Survey that personal income will rise from $58 billion in 1947 to $70 billion in 1965 attaining a level of $100 billion by 1980. From 1980 to 2010, although no great significance can be placed at the base year of 1980, personal income growth for the area will begin to move towards the national rate of growth, achieving $224 billion of personal income by 2010.

36. Population and Employment. Substantial increases in both population and employment have been and will continue to be closely associated with the historical and projected level of economic activity. The population of Delaware River service area in 1955 was 21,589,000 or about 13% of the total population of the nation of 164,303,000. Comparing the historical growth rate of population for the service area to the nation it is noted that while prior to 1900, population of the area grew at a rate equal to national growth, between 1900 and 1930 the area grew at a somewhat faster rate than for the United States, falling off to a slower rate over the most recent 25 years. The tapering off of population growth relative to the nation in recent years reflects to a great extent the major population expansion experienced in the West. While forecasts of population for the nation, based on a median expectation in line with the national historical trend,

anticipate a rate increase over the entire time span, from 1955 to 2010, of 1.5 percent per year, the projection of population for the service area embodies a rate of increase of 1.2% per year or 80% of the national rate. Population for the area is expected to rise to 25 million in 1965 to 30 million by 1980, attaining a level of 42 million by year 2010.

37. Total industrial employment for the service area in 1955 was 9,073,000 or about 14% of the total industrial employment of the nation of 65,250,000. The employment growth pattern for the area since 1900 as compared to the national growth pattern exhibits a pattern similar to the comparison of the area's population growth to U. S. population changes. Between 1900 and 1930 total industrial employment in the area doubled while for the United States it increased only about one and one-half times. However, from 1930 to 1955 the area's employment increased 20% while total United States employment increased 33%. The rate differential noted in the above comparisons generally indicates that the major share of industrialization in the service area occurred during the first quarter of the centurey while the slower rate of industrial employment in the area between 1930 and 1955 relative to the nation reflects the more rapid industrialization of newer and less developed areas outside the service area.

38. From a comparison of growth between the Delaware River service area and the United States for employment in selected industry groups over the last 25 years, it is evident that industrial growth was quite general among all major industries. While the overall increase in nonagricultural employment for the service area between 1930 and 1955 was close to 26%, the increase of employment in manufacturing during this period exceeded 32%. Of singular significance have been the increases in employment registered in four major water-using manufacturing industries, namely, food, chemicals, primary metals and paper. Between 1930 and 1955 combined employment in these industries rose 85% as compared to a rise of 76% in employment in these industries for the nation. The employment in the petroleum industry, another major water-user, plus the employment of the four industries enumerated above, constituted 24% of the total manufacturing employment in the service area for 1955.

39. Based upon projections of national employment and on a consideration of differential growth rates of individual industry groups in the service area relative to the corresponding national totals the area's industrial employment is projected to increase from nine million in 1955 to ten million by 1965 to more than twelve million in 1980 attaining a level of eighteen million by year 2010. Employment in the manufacturing industries is projected to increase at a rate somewhat in excess of the 100% growth projected for all industries during this 55-year span.

40. <u>Factors Sustaining the Level of Economic Development</u>. Whether or not this region can attain the high level of economic development as projected over the next half century will depend upon the favorable operation and interaction of a complex set of factors. The historical and projected level of economic development reveals that the potential for major expansion already exists within the service area. One factor upon which the service area will place considerable reliance to sustain and nourish growth will be the reasonable exploitation of her water resources in a balanced manner. The following paragraphs will present a discussion of the several water resource products as they relate to this regional economy indicating, where possible, the past and present use of water resources to satisfy certain demands as well as projections of future requirements for each water resource product.

41. A fundamental concept in planning for and the evaluation of proposed water resource development is that the goods and services to be produced by a project have value only to the extent that there will be a need and demand for those products. Accordingly, the definition of the water resource problems in terms of the various water resource goods and services that would satisfy specific economic and social wants of the people of the basin is a prerequisite to the formation of the optimum plan for development of the water resources. Studies in this area have revealed that in the next half century specific requirements may be placed on the water resources to meet demands for reduction of damages to the lands and improvements thereon from flooding; provision of additional water supplies to meet industrial, domestic, municipal and irrigation purposes; navigable waterways; production of electric energy via hydroelectric power installations; additional recreation opportunities; enhancement of fish and wildlife habitats; and the regulation of low flows to improve the quality and quantity of raw water available for in-place and withdrawal uses. The extent and nature of these demands have been specified in other appendices to this report and are summarized in following paragraphs. These demands are in line with the overall growth patterns projected for the Delaware River service area and its subregions as discussed above and presented in detail in Appendix B.

42. <u>DIMENSIONS OF THE FLOOD PROBLEM</u>. Problems arising from excess surface water are found on virtually all land areas. They originate at the point of impact of rain drops falling to the earth's surface and can be traced progressively through various stages from overland flows in the most elementary drainage patterns to the major channel and overbank flows in mature stream systems that convey excess waters to the sea. For purposes of this study, these problems have been placed in three categories, namely,

the overland flows at the uppermost headwater areas, local flood flows at the intermediate upstream areas and general flooding at the principal watercourse areas.

43. The magnitude of the flood problem generally can be measured in terms of average annual damages which in turn becomes a useful measure of the market for flood damage reduction. However, in the case of the overland flow problems in the uppermost headwater areas a different measuring technique is required as explained below in the discussion of those problems. The market for flood damage reduction measures arises out of personal, local, regional and national dependence on the life, property, products or services which are destroyed or damaged, or which are prevented from being produced or utilized as a result of floods. For the intermediate upstream and principal watercourse areas this market was expressed readily in terms of the dollar value of average annual flood damages. The average amount of damage that can be expected annually in any given area will depend on the magnitude and frequency of expected floods as deduced from past records. Average annual damages have been estimated for the intermediate upstream and principal watercourse areas of this basin on the basis of the percent expectancy in any one year of the various amounts of flood damage that would result from floods of all magnitudes up to those approaching the maximum probable flood. Based upon established procedures, taking into account stage-damage, stage-discharge and discharge-frequency relations, as detailed in Appendices D 4/, M 5/, and R 6/, estimates of total dollar value of average annual flood damages were computed for the several flood damage reaches and damage centers of the Delaware River and its tributaries. The magnitude of these damages are discussed in the following paragraphs.

4/ Appendix D, "Flood Damages", prepared by the U. S. Army Engineer District, Philadelphia, Department of the Army

5/ Appendix M, "Hydrology", prepared by the U. S. Army Engineer District, Philadelphia, Department of the Army

6/ Appendix R, "Water Control at Intermediate Upstream Levels", prepared jointly by the U. S. Army Engineer District, Philadelphia, Department of the Army, and the Soil Conservation Service, U. S. Department of Agriculture.

44. <u>Needs at Uppermost Headwater Areas</u>. The problems associated with overland flows in the uppermost headwater areas are related to the current and projected soil-cover complexes and land management practices. The damages from the rainfall-runoff regiman at this level arise from splash erosion surface compaction and sealing from rainfall impact with accompanying adverse effects on infiltration rates, sheet erosion, and gully erosion, all of which have adverse effects on land productivity. It has been found 7/ that the most reliable indices of the needs for treatment or corrective conservation practices are land capability classifications. These classifications consist of a systematic arrangement of different kinds of soil according to those properties that limit or restrict the use or determine the ability of the land to produce continuously without deterioration. The degree of permanent limitation imposed by soil characteristics and qualities necessarily affects the number and complexity of corrective practices, the productive capabilities of the land, and the intensity and type of land use. Capability classifications are made and used as the bases for the selection and application of land uses and treatment that will permit exploitation of the land's capability and keep it in condition for long periods of production. The latter involves the application and maintenance of conservation practices.

45. There are eight land capability classes, four of which are suited for cultivation. Classes in this category are differentiated according to the degree of permanent limitation in land use that is necessary because of natural land characteristics. They are, therefore, correlated with the general level of treatment or corrective practices needed. The eight land capability classes range from the best most easily used land, with least limitation in use (Class 1) to land suitable only for wildlife habitat, recreation or watershed protection purposes (Class VIII). The distribution of land use in the Delaware River basin, according to land capability classifications, is shown in Table Q-1.

46. The land use trends to be anticipated in the basin during the 50 and 100 year periods ahead are based on the projected land use for some 7-1/2 million acres of land in the basin as reported on in Appendix K. These land use trends are shown in Table Q-2 below:

7/ Appendix K, "Use and Management of Land and Cover Resources", prepared by the U. S. Department of Agriculture

TABLE Q-1

CURRENT DISTRIBUTION OF LAND USE BY CAPABILITY CLASSES

Land Class	Use Suitability	Characteristics	Conservation Needs	% in Basin	Areas in Use (1,000 acres) Cropland	Pasture	Woodland	Idle	Urban	Total
I	Cultivation	Level, well drained	No special problems	3.2	151.1	19.9	60.1	13.9	12.6	257.6
II	Cultivation	Gently sloping, good drainage	Strip crops, simple management	21.5	1,095.4	162.3	354.5	124.1	25.4	1,761.7
III	Cultivation	Moderately sloping or wet land	Strip crops, terraces drainage	21.4	841.6	156.4	609.6	126.5	15.7	1,749.8
IV	Hay or grass	Moderately steep, eroded or wet	Erosion protection, drainage	8.7	221.3	30.7	415.3	31.6	8.8	707.7
V	Pasture, forest, wildlife	Nearly level, often wet or stony	Maintenance of cover		-	-	Very little within basin	-	-	
VI	Pasture, forest, wildlife	Steep slopes, eroded, stony or wet	Cover, forest and habitat management	14.2	102.7	49.8	974.4	27.9	5.0	1,159.8
VII	Timber, recreation, wildlife	Steep slopes, eroded, stony or wet	Forest and habitat management	19.2	55.7	27.6	1,448.6	33.9	2.6	1,568.4
VIII	Recreation, wildlife	Steep slopes, very rocky, waste, marshes	-	2.0	2.4	0.8	126.4	33.3	3.4	166.3
Unclassed *	-	-	-	9.8	-	-	-	119.7	678.7	798.4
TOTAL				100.0	2,470.2	447.5	3,988.9	510.9	752.2	8,169.7
%				100.0	30.2	5.5	48.8	6.3	9.2	100.0

* Cities, roads, water and other.
Data from Table 12, Appendix K, rounded to nearest 0.1 1,000 acres

TABLE Q-2

CURRENT (1954-55) AND PROJECTED LAND USE IN MILLION ACRES (ROUNDED)
(Excludes unclassified lands in cities,roads,water and others)

Use	Area in Use at Years Shown			
	Current	1975	2010	2060
	(1)	(2)	(2)	(2)
Cropland	2.3	2.1	1.9	1.7
Pasture	.4	.4	.3	.3
Woodland	3.7	3.3	3.1	2.9
Idle	.3	.3	.3	.3
Urban	.7	1.3	1.8	2.2

(1) From Table 25 of Appendix K
(2) From Tables 39, 40 and 41 of Appendix K

It will be noted that the anticipated land use trends show a decrease in all classes of use except in the urban classification. This indicates a decreasing total requirement in the basin for corrective conservation practices with concomitant increases in runoff from expanding urban areas.

47. Needs at Intermediate Upstream Areas. The streams responsible for local flooding in these areas drain relatively small subbasins usually less than 25 square miles in extent. Damage from flooding along these small streams is generally local and often is of major concern only within the immediate area. These damages are sustained primarily by commercial and residential properties and their contents and, also, by highways, railroads and bridges. Lesser damages are sustained by agriculture and moderate damages are attributed to sedimentation and erosion. Studies of flood damages at the intermediate upstream level, as reported in Appendix R 6/ identified 36 small headwater streams in the basin with local reaches of moderate to high damage potential. Of these damage reaches 14 were found to sustain average annual damages of such magnitude as to indicate needs for protective measures. These 14 local damage reaches and the estimated average annual damages from flooding in each reach are given in Table Q-3 below.

6/ Appendix R, "Water Control at Intermediate Upstream Levels", prepared by the Soil Conservation Service, U. S. Department of Agriculture and the U. S. Army Engineer District, Philadelphia, Department of the Army

TABLE Q-3

AVERAGE ANNUAL DAMAGES IN LOCAL UPSTREAM REACHES

Stream	Tributary to	Average Annual Damage
East Brook	W. Br. Delaware River	$ 32,900
West Brook	W. Br. Delaware River	28,500
N. Br. Callicoon Creek	Delaware River	42,200
Brodhead Creek	Delaware River	432,700
Pocono Creek	Brodhead Creek	129,000
E. Br. Monocacy Creek	Lehigh River	67,200
Aquashicola Creek	Lehigh River	40,000
Mauch Chunk Creek	Lehigh River	24,600
Bushkill Creek	Delaware River	86,800
Little Martin's Creek	Delaware River	22,600
Tacony Creek tributary	Delaware River	6,200
Little Neshaminy Creek	Neshaminy Creek	109,300
Wissahickon Creek	Schuylkill River	39,000
Stony Creek	Schuylkill River	21,000
	TOTAL	1,082,000

48. Substantial damages from flooding are known 6/ to occur also in local reaches on five additional small streams in the basin. However, active watershed associations have approved protection plans in various stages of development and the damages in these local reaches are not considered to constitute "flood problems" in the sense employed herein. These five local reaches and the estimated average annual damage for each is given in Table Q-4 below:

TABLE Q-4

AVERAGE ANNUAL DAMAGES IN LOCAL REACHES
WITH APPROVED PROTECTION PLANS
(For natural conditions without effects of protection projects)

Stream	Tributary to	Average Annual Damages
Lackawaxen tributaries	Lackawaxen River	$ 30,200
Wallenpaupack Creek	Lackawaxen River	188,000
Paulins Kill Creek	Delaware River	21,500
Little Schuylkill River	Schuylkill River	120,000
Brandywine Creek	Christiana River	242,000
	TOTAL	601,700

6/ Ibid

49. Needs at the Principal Watercourse Areas. In analyzing the flood problem in these areas in the Delaware River basin consideration was given to three factors that generally contribute to the nature and extent of the flood threat along principal watercourses. They are (a) the topographic characteristics of the basin's flood plain, (b) the degree of physical development on the flood plain, and (c) the frequency and severity of floods.

50. As indicated in Appendix D the chief physical characteristics of the flood plains of the Delaware River basin are their relative narrowness. While the narrow limits of the flood plain may constitute natural barriers to extensive flooding, the present high degree of physical development in the flood plains aggravates the basin's flood problem. Studies of probable future trends of flood plain development indicate that substantial portions of the basin's principal flood plains are presently under heavy urban and industrial development. Since 1900, the occurrence of seven major floods has resulted in major losses to both life and property throughout the basin. The flood of August 1955, generally the largest of record throughout the basin, caused the loss of 99 lives and resulted in property damage and business losses in excess of $100 million. The susceptibility of this area to severe flooding from extratropical storms and hurricanes and the pressure of social and economic forces that tend to accelerate the use and redevelopment of the flood plain, will act in the future to accentuate the flood problems of this basin.

51. Considering only the recurring flood damages, after elimination of non-recurring damage in all reaches and damage centers in terms of 1958 development and 1958 prices, the average annual damage throughout the Delaware River basin amounted to $9,223,900. This represents the total current value of the flood control market in the sense that these dollar damages reflect the potential annual physical and business losses that are expected to be sustained over the long run in the absence of flood damage reduction measures. Existing flood control measures and those presently under construction will provide partial satisfaction of this market. It is estimated that upon completion these projects will have reduced the total average annual damages in the basin by $3,126,000. The remainder of $6,097,900 of average annual damages constitutes the total flood protection market in the basin yet to be satisfied. The geographic distribution of the remaining dollar damages by river reaches is shown in Table Q-5. This distribution by reaches and damage centers provides the basis for evaluating the effects of proposed water resources development in the reduction of flood damages.

TABLE Q-5

REMAINING* ANNUAL RECURRING FLOOD DAMAGES ON MAJOR STREAMS
(January 1959 price levels)

Stream	Reach	Average Annual Damage
Delaware River	Hancock, N. Y. to mouth of Lackawaxen R.	$ 30,100
Lackawaxen River	Prompton and Dyberry dams to mouth	144,000
Delaware River	mouth of Lackawaxen R. thru Port Jervis, N. Y.	
	main stream	235,700
	Shohola Cr. below Shohola Falls, Pa.	11,700
Neversink River	Bridgeville dam site to mouth	176,700
Delaware River	below Port Jervis to Tocks Island dam site	
	main stream	112,200
	Bush Kill below Girard dam site	20,300
Delaware River	Tocks Island dam site thru Easton, Pa.	
	main stream	814,200
	Brodhead, McMichaels and Pocono Creeks, below Pine Mtn., McMichaels and Bartonsville dam sites	132,000
	Paulins Kill below Paulina and Sarepta dam sites	27,800
	Bushkill Cr. below Belfast dam site	117,800
Lehigh River	Bear Creek dam to mouth	
	main stream	1,035,500
	Pohopoco Cr. below Beltzville dam site	3,500
	Aquashicola Cr. below Aquashicola dam site	136,800
	Jordan Cr. below Trexler dam site	8,000
Delaware River	below Easton, Pa. thru Trenton, N.J.	
	main stream	976,000
	Musconetcong R. below Hackettstown dam site	17,800
	Tohickon Cr. below Tohickon dam site	1,000
Delaware River	below Trenton, N. J.	
	main stream	391,200
	Crosswicks Cr. below Extonville, N.J.	1,100
	Neshaminy Cr. at and below Chalfont, Pa.	55,200
	Rancocas Cr. below Birmingham and Eayerstown	9,500
Schuylkill River	above Middleport to mouth	
	main stream above mouth of Perkiomen Cr.	596,600
	main stream below mouth of Perkiomen Cr.	698,900
	lower reaches of Maiden, Tulpehocken, Manatawney and French Creeks	14,200
	Perkiomen and Skippack Creeks below Spring Mtn. and Evansburg dam sites	39,800
Christina River	below major dam sites in basin	
	main stream and White Clay Cr. below Newark and Christiana dam sites	1,800
	Brandywine Cr. below Lyndell and Siousca, Pa.	288,500
	TOTAL	6,097,900

* Remaining after completion of projects presently authorized or under construction.

52. Since continued use and redevelopment of the flood plain of the Delaware River basin could significantly modify the damage potential situation in the several reaches of the basin, studies were undertaken to determine and evaluate probable future trends of flood plain development. The results of these studies, described in Appendix D disclose that by 2010 the prospective average annual damage potential throughout the basin may be expected to increase, under normal conditions, by 35% over the 1958 damage level to approximately $8,200,000. Future levels of average annual damage for the years 1980 and 2010 by major river reaches are summarized below in Table Q-6.

TABLE Q-6

PROSPECTIVE AVERAGE ANNUAL FLOOD DAMAGES 1/ BY REACHES OF PRINCIPAL WATERCOURSES FOR YEARS 1958, 1980 AND 2010

River Reach	1958	1980	2010
Delaware R. and tributaries	$3,420,600	$3,865,300	$4,515,200
Lehigh R. and tributaries	1,183,800	1,290,300	1,444,200
Schuylkill R. and tributaries	1,349,500	1,659,900	2,078,200
Lackawaxen R. 2/	144,000	144,000	144,000
BASIN TOTAL	6,097,900	6,959,500	8,181,600

1/ 1959 price level
2/ No significant flood plain development anticipated in Lackawaxen River basin

53. NEEDS FOR SUPPLIES OF WATER. In a highly populated and industrial region, characteristic of the Delaware River service area, the availability of supplies of water of sufficient quantity and quality is one of the most important products of water resources development. Domestic and municipal use of water in urban and rural residences, commercial establishments, and industrial plants has long ago risen beyond more subsistence levels. The rising standard of living brought with it increased use of water consuming appliances such as air-conditioning installations, automatic dishwashers, home laundries, garbage grinders, lawn sprinklers and swimming pools. While evidence indicates that far from all households now posses such devices, if trends of continued increases in real per capita personal income and acceleration of new home building are sustained in the future, it may be expected that an increasing share of homes will soon possess many of the above mentioned water-using devices. The installation of water-using devices has also gone hand in hand with the improvement of working conditions in commercial and industrial

establishments. These forces have an accelerating effect on per capita water use rates. When this is coupled with the projected doubling of population over the next fifty years, there is little doubt that increasing demands on the water resources of the area to satisfy the water needs for domestic and municipal purposes will persist.

54. The industrial production processes of this region require tremendous withdrawals of water, accounting for more than 80% of all water withdrawn for all purposes in the basin. The preponderance of heavy water using establishments located in this region's industrial complex serves to dramatize the importance of maintaining adequate supplies of water for use in the various industrial processes. Major water using industries such as paper, food chemicals, petroluem and primary metals, accounting for 24% of manufacturing employment in the water service area in 1955, may require from one million to nine million gallons of water per year per employee. Future expansion of industry and more specifically of the heavy water using industries will depend upon provision of adequate water supplies. Although future decisions by industry to locate in the area depend upon many factors, the availability of water supplies can be expected to exert considerable influence.

55. Agriculture as an industry in this region contributes only small amounts both to total employment and personal income. However, the importance of this industry to the area should not be minimized. Aside from directly providing a major share of food products consumed in the basin, agriculture is an important feeder industry for the food processing industries of the region. Water supplies for irrigation, livestock and other rural farm purposes are reported in Appendix G 8/. Although small in comparison to the needs for domestic-municipal and industrial use, the water needs of agriculture, nonetheless, are crucial if that industry is to maintain its position within the regional economy.

56. Projections of Gross and Net Water Needs. Separate projections of municipal-domestic water demands, industrial requirements and irrigation, livestock and other rural needs for each of the eight economic subregions of the Delaware River service area were prepared for the years 1965, 1980 and 2010. These current and projected gross water demands represent the total water required on the average to be withdrawn from several sources to meet the daily needs of all individuals, commercial establishments, industries, irrigation and livestock within each subregion - the total water

8/ Appendix G, "Water for Irrigation and Rural Use", prepared by the U. S. Department of Agriculture.

water market for the service area. In the final definition of the water supply market to be satisfied from the water resources of the Delaware River basin those portions of the Delaware River service area within the river basin boundaries were subdivided into six water problem areas based on the economic subregions and the basin geography. Portions of the service area outside the Delaware River basin boundaries were subdivided into three additional water problem areas. These nine water problem areas are shown on Plate Q-2. Gross water needs were distributed among the water problem areas and by taking into account present ground and brackish water withdrawals, diversions, consumptive use and recycling factors, repetitive uses, and existing minimum stream flows, it was possible to reduce present and projected gross water needs to net needs from surface sources within each water problem area for each of the projected target years. These net surface water requirements for the six water problem areas within the basin boundaries represent that portion of the water supply market within the basin proper that could be satisfied by increasing stream flows or otherwise distributing the waters of the Delaware River basin. Detailed description of the procedures used in arriving at these projections are discussed in Appendix P 9/. The projections of net surface requirements are summarized below in Table Q-7.

57. Frequency of Water Needs. The needs for supplies of water as defined by the net surface requirement described above were based on the volumes required to augment present flows found to prevail 95% of the time under existing conditions of development and diversion. Such needs may be based, also, on the statistical frequency of various volumes required to augment natural flows for needed supplies of water. In this latter case the optimum degree of satisfaction of the water requirements could be based on evaluations of the storage requirements at various frequencies. However, precise evaluations are not practical and the frequency of satisfaction is usually selected on the basis of existing practice or other considerations. Because of the conservatism inherent therein, the 95% basis was adopted for this investigation.

58. Other Factors Effecting Demands for Water. Closely related to the quantitative problem of augmenting surface stream flows to satisfy the several water demand requirements in the water problem areas is that of water quality and stream pollution. It must be assumed that the maintenance of water quality and reduction of stream pollution will be essential if complete satisfaction of the water supply market is to be realized. Aside from

9/ Appendix P, "Gross and Net Water Needs", prepared by the U. S. Army Engineer District, Philadelphia, Department of the Army.

TABLE Q-7

NET SURFACE WATER REQUIREMENTS IN WATER PROBLEM AREAS
WITHIN THE DELAWARE RIVER BASIN BOUNDARIES

Use		1965	1980	2010
UPPER DELAWARE AREA				
Domestic and Municipal	(mgd)	17.3	24.0	42.9
Self-Supplied Industrial	(mgd)	12.3	18.3	38.3
Agricultural	(mgd)	3.3	3.9	4.0
Total	(mgd)	32.9	46.2	85.2
Reqd. Surface Water Augmentation	(cfs)	0.0	0.0	0.0
MIDDLE DELAWARE AREA				
Domestic and Municipal	(mgd)	4.5	6.3	12.1
Self-Supplied Industrial	(mgd)	29.1	43.1	94.2
Agricultural	(mgd)	Included in Trenton-Phila.		
Total	(mgd)	33.6	49.4	106.3
Reqd. Surface Water Augmentation	(cfs)	0.0	0.0	0.0
LEHIGH AREA				
Domestic and Municipal	(mgd)	41.3	58.4	108.4
Self-Supplied Industrial	(mgd)	194.0	228.5	364.2
Agricultural	(mgd)	2.4	2.8	2.9
Total	(mgd)	237.7	289.8	475.5
Reqd. Surface Water Augmentation	(cfs)	48.3	129.0	416.0
UPPER SCHUYLKILL AREA				
Domestic and Municipal	(mgd)	52.5	72.9	132.7
Self-Supplied Industrial	(mgd)	123.3	153.3	197.7
Agricultural	(mgd)	Included in Trenton-Phila.		
Total	(mgd)	175.8	226.2	330.4
Reqd. Surface Water Augmentation	(cfs)	0.0	56.0	217.0
TRENTON-PHILADELPHIA AREA				
Domestic and Municipal	(mgd)	583.8	812.8	1445.8
Self-Supplied Industrial	(mgd)	1034.7	1141.0	1155.3
Agricultural	(mgd)	19.3	24.4	24.4
Total (Incl. surface losses)	(mgd)	1917.5	2377.6	3415.7
Reqd. Surface Water Augmentation	(cfs)	0.0	491.0	2100.0
WILMINGTON AREA				
Domestic and Municipal	(mgd)	48.2	72.0	151.4
Self-Supplied Industrial	(mgd)	933.0	1549.0	2744.0
Agricultural	(mgd)	12.1	14.6	14.6
Total	(mgd)	933.3	1635.6	2910.0
Reqd. Surface Water Augmentation	(cfs)	1380.0*	2380.0*	4350.0*
Reqd. Fresh Water Augmentation	(cfs)	0.0	38.7	526.0

* Gross requirements to be satisfied by fresh and brackish water.

their importance in terms of water supply problems, water quality and pollution considerations bear heavily on the use of the streams for recreation and commercial fishing as well as on the intangible aesthetic value of clean streams. In defining the importance of water quality and pollution abatement as yet another set of water resource products contributing to the well-being of the area, consideration must be given to the several quality requirements placed upon the waters of the Delaware River basin by other water resource market requirements. Provision of raw water to satisfy domestic-municipal uses calls for water of at least safe and potable quality. Industrial processes may require water of the highest quality for use in the food processing industries or a substantially lower quality when the water is used for some cooling purposes. Quality requirements will differ from one use to another and vary according to the point at which raw water withdrawals are made within the basin. In almost all cases, excepting most cooling water applications, varying degrees of treatment are required to bring the raw water to the quality level desired. In contemplating long range comprehensive development of the water resources of the basin, water quality and pollution abatement as resource products have been integrated generally into the water supply market discussed above. As an assumption in the definition of that market, it was felt that the present "clean stream" program would keep pace with contemplated development and use of the water resources of the basin. As a guide in evaluating those measures that could satisfy the net surface water requirements for each problem area, careful consideration was given to the possible effects on water quality and pollution abatement via stream flow augmentation. In the absence of quantitative definition of these needs, it was assumed, for planning purposes, that future augmentation of stream flows, of sufficient magnitude and proper character to preserve present raw water qualities would satisfy that portion of the water quality and pollution abatement market susceptive to satisfaction by control of surface waters.

59. The problem posed by salinity intrusion in the lower Delaware River and Bay and tidal portions of the tributaries is of importance, also, in consideration of the water quality aspects of the water supply market. The upstream limit of harmful salinity intrusion in the estuary extends to about the Delaware-Pennsylvania state line. During periods of extreme low fresh water flows, the salt water may intrude as far upstream as Philadelphia. The salinity front 10/, while not affecting sources of water currently being utilized for domestic supplies, continually poses problems for water-using industries downstream from Eddystone in the Chester-Marcus Hook area. During periods of high salinity intrusion, many industries in the area incur additional costs for chemical treatment

10/ Based on the 50 isochlor.

to remove the objectionable salinity constituents, for storage of fresh water for use when the quality of the river water has deteriorated significantly, and, in some cases, for curtailed operations until the quality of the water returns to tolerable levels. The increase of pollution problems as a result of salinity intrusion over the past 25 years cannot be completely attributed to the tidal effects in the estuary. The discharging of municipal and industrial wastes into the Delaware estuary contributes to the salinity problem. The resolution of this salinity problem seemed to constitute a means for satisfying the rapidly expanding industrial water demands in this area. However, because of the extreme complexity of this problem it was concluded that any practical comprehensive plan to be devised at this time for satisfying the overall water supply market, could be expected to do no more than stabilize the salinity front at its present locality with supplemental measures and programs to mitigate salinity problems during dry periods.

60. Needs Arising from Non-Withdrawal Uses. Thus far the definition of the water supply market has been limited to a discussion of factors related directly or indirectly to withdrawal uses. Of equal importance in such a definition are the non-withdrawal uses such as navigation, recreation, conservation of fish and game and waste disposal. Water supply in this sense is employed in place with no requirements for withdrawals. The requirements to be placed on the water resources of the basin for non-withdrawal uses are directly related to the market for those products associated with given non-withdrawal uses. As examples, although portions of the recreation market may be satisfied by enhancement of recreational opportunities at proposed reservoir projects, there may be non-withdrawal requirements on the storage pool to maintain water quality and reduce pool level fluctuations. Recent successes in improving the stream quality of the Schuylkill River has resulted in the improvement of sport fisheries. Maintenance of sustained minimum flows in the streams of the Delaware River plays an important role in their capabilities for carrying off and diluting wastes discharged into them. While it is not possible to forecast non-withdrawal use requirements in a manner similar to the projections made for withdrawal uses, this sector of the overall water supply market has been taken into account in the analyses of the other water resource product markets that rely upon the water supplies of the basin.

61. Although the future pattern of economic activity for this area may rely on factors dissociated with provision of supplies of water, it is clear that scarcities of future supplies servicing the several withdrawal and non-withdrawal uses could materially retard or permanently impair growth potentials.

62. <u>THE MARKET FOR HYDROELECTRIC POWER</u>. Electrical energy produced at water resource development projects is marketable within the practical distribution areas of the projects. In developing estimates of present and future power requirements for the Delaware River service area the geographic boundaries of the power market were made consistent with power supply areas designated by the Federal Power Commission. As indicated in Appendix F 11/, the power market of the service area embraces all of Power Supply Area 4 and approximately 70% of Power Supply Area 5. This area is currently being served by 19 principal electric utilities.

63. <u>Present and Future Power Requirements</u>. Present total power requirements within the service area power market area for 1957 called for the generation of over 55 billion KWH to serve farm, non-farm residential, commercial, industrial and all other consumer classes. Utility peak demands during 1957 in this power market area required in excess of 11 million kilowatts. Taking into account projected increases in population, households and industrial development as well as consideration of recent trends in power utilization, the Federal Power Commission prepared estimates of future requirements for each class of utility service for the period 1960-1980. Estimates of total utility requirements for the period from 1980 to 2010 were made by extending the indicated growth trends evident over the period from 1940 to 1980. By 2010 it is estimated that electric power requirements will increase nearly nine times the present level. Past and estimated future utility power requirements in the Delaware River service area period 1950-2010 are shown in Table Q-8.

64. <u>Future Capacity Requirements</u>. In consideration of power markets which could absorb the output of potential hydroelectric projects on the Delaware River and its tributaries, the Federal Power Commission developed estimates of future capacity for Power Supply Area 5, presently providing the major bulk of utility service to the area through the Pennsylvania-New Jersey-Maryland Interconnection. Taking into account existing supply, estimated future load and reserve requirements, scheduled additions to capacity and expected retirement of existing capacity, it was estimated that by 1965 the utilities of the area would have to install an additional 1,963 megawatts 12/ and by 1980 over 16,500 megawatts of additional capacity would be required. Similar estimates were developed for that portion of the power supply market currently

11/ Appendix F, "Power Markets and Valuation of Power", prepared by the Federal Power Commission.

12/ One/megawatt equals 1,000 kilowatts.

TABLE Q-8

PAST AND ESTIMATED FUTURE UTILITY POWER REQUIREMENTS IN DELAWARE RIVER SERVICE AREA 1950-2010

Year	Energy for Load (Millions of Kwh)	Peak Demand (Thousands of Kw)	Load Factor (Percent)
1950	35,028	7,403	54.1
1955	49,027	10,145	55.2
1957	55,142	11,106	56.7
1960	66,600	13,440	56.4
1965	88,100	17,490	57.5
1970	113,900	22,230	58.5
1975	144,500	27,720	59.5
1980	180,400	34,000	60.4
1985	222,100	41,500	61.3
1990	270,300	49,600	62.2
1995	325,700	59,000	63.0
2000	389,000	69,500	63.7
2005	461,200	82,000	64.3
2010	543,500	96,000	64.8

served by the Interconnected System of the New York State Electric and Gas Corporation. By 1965 an additional 260 megawatts of capacity will be required while by 1980 requirements for new capacity are expected to increase to nearly 1,100 megawatts. The estimates presented above are discussed in detail in Appendix F.

65. The Role of Hydroelectric Power. As of December 31, 1957, hydroelectric developments accounted for only 5.6% of the net generation capacity for utility plants in Power Supply Area 5. Installed hydroelectric capacity of generating plants of the Interconnected System of New York State Electric and Gas Corporation, as of 1957, amounted to 2.5% of that system's total installed capacity. This percentage is somewhat less in terms of dependable capacity. In consideration of potential hydroelectric development providing partial satisfaction for required additional capacity, Federal Power Commission has indicated that for proposed hydro development at water resources projects under consideration, there will exist a ready market for all energy that can economically be produced at these sites. However, in terms of the total additional capacity required, the contribution of the two most feasible hydroelectric installations at projects under consideration is relatively slight. For planning purposes consideration has been given to the several hydro potentials of the basin as measures that might provide partial satisfaction to overall power market.

66. THE RECREATION NEEDS. The demands for recreation opportunities are generated, primarily, by the people of the basin and the surrounding areas. To determine the extent to which the development of the recreational products of the water resources of the Delaware River drainage area might be justified, the recreation market was defined quantitatively in terms of expected growth, in terms of geographic characteristics, in terms of visitor-day magnitude, and in terms of seasonability and other peculiarities. Details of these definitions are presented in Appendix W 13/. The types of recreational activity included here are those generally classified as one-day outings, overnight outings and vacations away from home. In 1955 recreation activity in the Delaware River service area amounted to 345,500,000 visitor-days of which 137,700,000 visitor-days or 40 percent were one-day outings, 75,800,000 visitor-days or 22 percent were overnight outings, and 132,000,000 visitor-days or 38 percent were vacations away from home. The recreation activities include swimming, picnicking, sightseeing, going to the beach, fishing, hunting, camping, visiting museums, and boating. Engagement in these activities may be at Federal, state, county, local, or individually sponsored parks,

13/ Appendix W, "Recreation Needs and Appraisals", prepared by the National Park Service, Department of the Interior, and U. S. Army Engineer District, Philadelphia, Department of the Army.

forests, game and fish lands, picnic grounds, historical sites and museums, resorts, seashore areas and pleasure tours. In the main, the recreational activities of primary concern here are those generally considered non-revenue producing and most often provided at public expense.

67. Basis for Projecting Recreation Needs. As explained in detail in Appendix W, the projection of the gross market for outdoor recreation was derived from historical trends of increased per capita recreation activity, as indicated by available attendance data for state parks, applied to projections of population. This assumes that the rate of increase of state park use is indicative of the rate at which the people are willing to convert economic gains into outdoor recreation activity as is generally characteristic of all consumer behavior.

68. A comparison of specific activities considered among the most important by the people of the basin, with activities that may be provided in multiple-use water control developments, showed that projects of the type under consideration in the survey approach state park conditions insofar as meeting the recreation demands is concerned. Such similarity suggested that projections of recreation demands, within the period under consideration, would be more accurately indicated by trends noted in state park use than would be the case with other types of available recreation experiences.

69. Projections of hunting and fishing days were based on (a) rates of increase in the average annual number of licenses per capita, (b) the projections of population and (c) the number of fishing and hunting days engaged in per license buyer as indicated by 1955 experience. Note that these approximations of future hunting and fishing days do not include any projected changes in the number of fishing and hunting days by each participant.

70. Projections of Outdoor Recreation Needs. The projections of outdoor recreation needs of the people of the Delaware River service area derived in the manner indicated above are shown in Table Q-9 below:

TABLE Q-9

PROJECTED OUTDOOR RECREATION NEEDS OF THE DELAWARE RIVER SERVICE AREA
(In 1,000 visitor-days or man-days)

Item	1955	1965	1980	2010
State Park Attendance	33,570	55,800	98,700	227,000
Fishing	33,380	43,200	61,200	111,900
Hunting	14,240	18,400	25,000	43,000

The composition of these recreation needs would not necessarily reflect a demand to provide for types of activity in the relative proportions indicated in the projections. Rather the real requirement here would be to provide for outdoor recreation opportunity under the best conditions possible for the maximum number of people.

71. <u>Net Market for Recreation Products of Water Resources Development</u>. Day outings are primarily family affairs and it is this category of outdoor recreation that water resources developments make their principal contribution. Picnicking and swimming facilities are in greatest demand by people on day-outings. Studies reported in Appendix W indicate that there was an excess demand of 358,000 people over capacities of state park type facilities to accommodate normal summer Sunday visitors in 1955. This excess was defined as the need for outdoor recreation facilities for the Delaware River water service are at the 1955 level. It should be noted that overnight or weekend use has not been taken into account in this analysis.

72. If state park attendance continues its present trends with respect to population and per capita recreation pursuits it is expected that annual park use in the service area will increase from the present 33,570,000 visitor-days to about 227,000,000 visitor-days at year 2010. An increase of this magnitude would require that recreation facilities for 2,933,000 people be provided by year 2010 in addition to facilities for the 358,000 deficit indicated to exist in 1955.

73. <u>ECONOMIC RATIONALE FOR SATISFYING THE NEEDS FOR PRODUCTS OF WATER RESOURCES DEVELOPMENT</u>. These planning studies have been directed persistently toward the design of a sound and reasonable plan for the control and restraint of the uneven flows of the Delaware River to the practical and economical extent required for the foreseeable uses of surface water in the future thereby permitting the continued economic expansion of the Delaware basin community. As progress was made towards the fulfillment of this objective, the design tended not only towards a plan best adopted to the physical features of the basin but, also, towards a plan whose production of goods and services would serve as a positive force contributing to the area's social and economic growth over the next fifty years or more. In consideration of this latter end a serious attempt was made to associate the production of goods and services from water resources developments with the regional economic growth. Although such products as flood control, water supply, recreation, hydroelectric power generation, improved fishing and hunting opportunities and improved water quality represent only a few of the great number of factors that define the projected growth pattern, the general effects of the production of such goods and services on the economy of the region was recognized as a necessary planning consideration.

74. A basic premise of the appraisal of these effects is that there exists an ever expanding market for the consumption and utilization of the goods and services. The history of economic development and the projected growth pattern as presented in the Economic Base Survey in Appendix B unquestionably supports this proposition. Also, while certain goods and services, such as municipal supplies of water, may be produced only through the control and utilization of water resources, others, such as electric generation, can be secured through alternative developments not normally associated with water resources. Precise definition of the overall impact of the production of goods and services from water resources on the economy of the Delaware River basin was found to be beyond the planning requirements. That a need exists for their production is clear. Given limited physical resources to develop a river basin, it is necessary to establish guide lines that define practical parameters for the production of any given type of goods or services through water resources projects.

75. The diversity of the products of water resources development, how they are used, how they nourish other activities, and many other factors completely disassociated from water resource projects as such, all contribute to the economic growth of the region. While it is apparent that the provision of the products of water resource development alone cannot insure economic growth of a region, the needs for these products do expand with growth. Accordingly, the plan for development of the water resources must assure that a properly balanced supply of these products will be available as the economic growth pattern demands. If the production of any given product of water resources is presently excluded because of economic infeasibility, the overall economic well-being of the basin and water service area may eventually require a change in the use of the productive measures to meet the balance dictated by new and unforseen conditions.

76. A plan for development of the water resources of the Delaware River basin to serve as a positive force contributing to the area's social and economic growth must be based on objective appraisal of the potential projects and available measures in the basin for producing the needed goods and services. The considerations and findings of that appraisal are reported on in the following sections of this appendix.

V MEANS OF SATISFYING NEEDS FOR WATER RESOURCES PRODUCTS

77. BASIC MEASURES UNDER CONSIDERATION. This section will report on the potential measures considered for use, directly or indirectly, to produce with minimum investment in productive resources, the goods and services required to fill the needs defined above. With few exceptions the needs under consideration here derive from excesses and deficiencies of surface water supplies and from a dearth of developable surface waters at favorable localities for water based activities. From this it would appear that these needs could be met by simple basic measures to ameliorate the excesses and deficiencies of surface flows. From the standpoint of a balanced comprehensive plan to produce the desired goods and services, measures to impound and regulate the surface waters seem to offer the most likely potentials for satisfying all or a major portion of the needs for the products of the basin's water resources. This is not to say, as will be explained later, that such measures are the only means of attaining the desired goods and services.

78. The impoundment and regulatory measures cited in the paragraph above range from the various physical features of land management in the uppermost headwater areas; through small detention reservoirs in the intermediate upstream areas; to major impounding reservoirs in the principal watercourse areas. While these measures are fundamentally for impeding, impounding or regulating surface waters, their use for production of the several needed goods and services involves distinct differences. For example, excess flood waters need be impeded or impounded only for periods of relatively short durations, say, hours, days or even a few weeks. Similarly, supplies of water to meet extreme peaks in domestic and industrial demands of short duration need be impounded for only a few days or weeks. On the other hand, excess water impounded for most average water supply purposes, hydroelectric power generation and the provision of recreation opportunities usually are carried over for many months and often for years. The expressions "short-term storage" and "long-term storage" are used, herein, to designate these two variations in the use of reservoir impounding capacities. It must be recognized, however, that in actual practice there is no distinct line of demarkation between these two types of basic storage capacities in comprehensive storage developments. In fact, the two types of storage are more properly separated by a "grey zone" that modestly encroaches on the upper portions of the long-term storage and on the lower portions of the short-term storage and with proper operating techniques may be used for either purpose as the exigencies demand. The full appraisal of this "grey zone" has not been undertaken as a feature of this study because of the great amount of

detailed "hindsight" operation studies involved in procedures presently available. The omission of these values is on the side of conservatism in the economic appraisals.

79. In view of the apparent high potentials afforded by impounding measures and the importance that such measures would assume in studies to define the comprehensive plan of development an inventory was made, at an early date, of the possible reservoir projects in the basin. This inventory was in two parts, namely, small upstream reservoirs in the intermediate upstream areas and major reservoirs in the principal watercourse areas. The former was based on map studies and field reconnaissances and a total of 386 potential small dam and reservoir sites with drainage areas of 1 to 20+ square miles were listed for the basin. The details of this study and the locations of the small dam potentials are given in Appendix R. The inventory of major reservoir potentials was based on sites considered in 35 prior reports dealing with water resources developments in the basin and on additional map and field studies made in the course of this investigation. A total of 193 major dam and reservoir sites were identified initially in this inventory. The location of each of the major dam sites thus identified as shown on the map, plate Q-3.

80. The basic storage potentials identified in these two studies, plus the land management potentials reported in Appendix K, constitute a comprehensive inventory of the water impeding and impounding potentials for all levels of development in the basin. However, it must be noted that a great number of very small reservoirs with drainage areas of one square mile (640 acres) or less have been omitted from the inventory of basic storage potentials. This omission was decided upon after careful consideration of the number of very small reservoirs to be appraised, the localized nature of the effects of projects in this category and the role of the very small reservoirs in the broad planning procedures to define the optimum plan of development for the basin. Also, it was recognized that complete evaluation of the very small reservoir potentials could be readily accomplished under programs approved by PL566 and PL 685 as discussed in Appendix R when the local needs for measures of this type arise.

81. <u>ALTERNATE WATER CONTROL MEASURES AND SUPPLEMENTAL PROGRAMS</u>. The basic measures discussed above for controlling surface waters appear to offer optimum potentials as basis for a balanced water resources development capable of producing a multiplicity of needed goods and services. However, the planning goals require, further, that the development be accomplished in such manner as to maximize the output with minimum investments to pro-

ductive resources. To assure that this objective be realized to the greatest practicable extent, consideration was given not only to the relative efficiencies and costs of the various basic water control measures but, also, to the relative efficiencies and costs of all practical alternate measures and supplemental programs. Involved in the latter are programs to alleviate flood damages by the controlled use and development of the flood plains and the protection of local centers of flood damage by such alternative measures as channel improvements, flood walls or levees. As a basis for determining their role in the optimum plan of development, the efficiencies and costs of these programs and alternative measures need be expressed only in terms of relative values with respect to other measures under consideration. Appraisal of them in general terms was made for that purpose. These appraisals are discussed in the paragraphs below.

82. <u>Relative Efficiencies and Economics of Impounding Measures</u>. As indicated above some 576 impoundment potentials were inventories in the small and major dam and reservoir categories. It was apparent that a forthright appraisal of all of these impoundment potentials on a coequal basis would entail for each potential impoundment, an assembly of data from the field and analytical computations in the office. The possible use of modern electronic computers seemed to offer only modest help in accomplishing such a task because of the extent and nature of data to be assembled and the individual estimates of cost and worth (each requiring degrees of judgment) needed for use in a computer. Furthermore, initial screenings on obvious bases showed such appraisals to be unwarranted. However, a general appraisal was made of the two broad categories of inventoried impoundment potentials to determine their relative effectiveness and cost of controlling surface waters. This is reported in the following paragraphs. It must be emphasized that the only interest in comparing the two categories, distinguished primarily by the size of the impoundment projects under consideration in each case, stems from the requirement to formulate the plan of development for producing the needed goods and services on the basis of efficiency and relative economy.

83. It is impractical from the standpoint of hydrology to generalize with regard to the relative efficiencies involved in modifying flood stages at downstream damage centers by means of (a) a number of small reservoirs clustered or scattered in the tributary basin or (b) an equivalent single major reservoir on the main stream of that basin. A major problem here lies in the physical characteristics of the individual flood hydrographs of the tributary basin and their relative magnitude and timing with respect to runoff from other portions of the basin above the damage center. Also, when the damage center under study lies

within the tributary basin, the effects of timing are minimized. These effects were evident in a detailed study made to determine the probable modifications of the basin project flood flows and the actual August 1955 flood flow by small and large impoundments in the Tulpehocken Creek basin, a tributary of Schuylkill River, near Reading, Pennsylvania. In this study the impounding structures in both categories were assumed capable of controlling 128.5 square miles of the 211 square miles above the U.S.G.S. gage on Tulpehocken Creek near Reading. Because of its elongated shape, the uncontrolled drainage area below the eight small reservoirs produced a peak runoff as much as 26% lower than the peak runoff from the more compact area of the same size below the single large reservoir. However, the higher peak runoff occurred some six hours earlier than the lesser peak and this difference in peaking times tended, with respect to downstream flood flows on the Schuylkill River, to obviate the differences in the tributary peaks because the slower peak runoff more nearly coincided with the peak runoff from the upper Schuylkill River. Of course, for local effects along the lower reaches of Tulpehocken Creek, the lower peak would be advantageous. This study, details of which are on file in this office, supported the view that from the standpoint of hydrology, the relative efficiency of the two categories of impoundment depends on conditions attending individual cases and is not susceptible of generalized appraisals.

84. The relative efficiency of the two general categories of impoundment to yield increase flows for water supply purposes is better defined than in the case above. The surface water availability studies reported in Appendix M and the optimum storage yield relations for small reservoirs presented in Appendix R constitute adequate bases for appraising the relative efficiency of the two impoundment categories under study. These studies show that at the eight small reservoirs studied in the Tulpehocken Creek basin, a total of 46,000 acre-feet of storage would yield, on an optimum basis, about 88.7 mgd. The same storage in the equivalent single reservoir would yield about 112.5 mgd which is about 27% greater than the yield from the eight small projects. This is typical of the relative yields of small and major impoundments studied in various phases of this investigation. It should be noted that under these conditions, development plans to meet anticipated surface water needs by yields from small reservoirs probably would require as much as 25% more storage (at additional small reservoir projects) than would be required to meet the same water needs by yields from major impoundments. If the equivalent yield must be obtained through added storage at the same small reservoir projects, the storage requirements may be increased as much as 400% because of the storage-yield relations for developing higher percentages of the ultimate yield from the drainage areas above the projects.

85. The relative efficiencies of the two categories of impoundment to satisfy the needs for hydroelectric power and recreation opportunities are susceptible only to general pro and con appraisals. In the case of hydroelectric power the potential at any impoundment is a matter of the range in available head and flow. The small reservoirs and most of the major impoundments lack the head and flow to make them attractive for generation of hydroelectric power. On the other hand, all impoundments of water, regardless of dimensions can be held to have a degree of recreational potential. The extent of this potential depends, as explained in Appendix W, on many features of the individual projects. In appraising these potentials, consideration was given to such factors as accessibility, water surface area, general attraction, and the availability of recreation and sanitary facilities. From the viewpoint of regional recreation demands it appears that these factors favor the major impoundments, particularly with regard to water surface area and attraction. However, studies reported in Appendix R show that some of the small reservoirs provide excellent recreation potentials to meet local demands only, provided the proper access lands and facilities are provided. In this connection, it should be noted that the estimated additional land required to accommodate recreationists at two small reservoirs studied in detail varied from 140 to 670 acres.

86. The preliminary estimates of project cost made during early phases of this investigation were relied upon for indications of the relative economies of water resources development by the two general categories of impoundment under consideration. A comparison of the preliminary cost estimates for small and large impoundments in the Tulpehocken Creek basin showed that one acre-foot of storage in the small projects cost an average of $368. while similar costs in an equivalent major project was found to be $192. The structures under consideration here were designed to include high standards of structural safety and the resulting comparable storage costs may seem indicative of the relative economies of development by the small and large impoundments. However, the cost of storage in small reservoirs must be adjusted to compensate for the relative inefficiencies of this type of project in yielding increased water to meet projected water supply needs. The relative economies of the two categories of impoundment were explored further by study of comparative costs for a group of 42 small reservoirs reported on in Appendix R and for a group of 15 major reservoirs in one of the plans of development considered for the basin. The preliminary costs for the small projects, designed for moderate hazard conditions downstream, showed an average cost of $312. per acre-foot of storage based on a total of 44,900 acre-feet of storage. The preliminary costs for the major impoundments, as designed for high hazard conditions downstream, showed an average cost of $191. per acre-foot of

of storage based on a total of 1,665,000 acre-feet of storage. In this case, the cost per unit of storage in the small reservoirs, also, must be adjusted for their relative inefficiencies for water supply purposes. Such an adjustment would place the average cost of storage for water supply purposes in small reservoirs at about $420. per acre-foot of storage.

87. A disparaging element of the cost comparisons above is that the unit cost for storage in the major impoundments is based on 1,665,000 acre-feet of capacity while the comparable figures for small reservoirs are based on a total of only 33,500 acre-feet of storage. The total storage potential of 293 small reservoirs found to be practical after initial screenings of the 386 small reservoirs inventories, is only 709,300 acre-feet. The geographic distribution of the drainage areas above these small reservoir sites and the total capacities and surface areas involved are shown in Table Q-10.

TABLE Q-10

POTENTIAL SMALL RESERVOIR CAPACITIES
IN MAJOR GEOGRAPHIC AREAS

Region	Total D.A. above Sites (sq.mi.)	Total Capacity (ac.ft.)	Total Surface Area (acres)
E.Br. Delaware R.	128.1	41,940	1,669
W.Br. Delaware R.	133.5	83,796	2,360
Hancock to Port Jervis	427.1	151,928	7,044
Port Jervis to Belvidere	184.1	121,261	5,085
Belvidere to Trenton	92.8	35,913	1,413
Trenton to Philadelphia	63.1	25,615	1,319
Lehigh River Basin	134.0	46,820	2,768
Schuylkill River Basin	402.2	141,050	8,602
Philadelphia to Bay	94.8	60,953	2,517
TOTAL	1,660.0	709,300	32,800

It was found as the planning studies progressed that the small reservoir potentials included in the inventory were inadequate as complete alternatives for the major impoundments under consideration. For example, the Hawk Mountain project on East Branch of Delaware River would control a net drainage area of 440 square miles and provide 293,000 acre-feet of storage with a maximum area inundated of 5,300 acres. For comparison the small reservoir potentials above that site would provide a storage of only 35,500 acre-feet with an

inundated area of 1,345 acres. The Tocks Island project under study for development on the Delaware River would provide 770,000 acre-feet of storage with an inundated area of about 15,000 acres. The total small reservoir potential above Belvidere would provide only 312,000 acre-feet of storage and inundate 12,700 acres. Likewise three major reservoirs under consideration in the Lehigh River basin would provide 152,000 acre-feet of storage and inundate about 3,600 acres while the small reservoir potentials in the basin would provide only 37,000 acre-feet of storage and inundate 1,718 acres. Since the 386 sites exhausted all practical locations offering moderate downstream conditions with regard to flood threats and reasonable relocation and real estate costs, it is apparent that additional small reservoir sites to increase the storage potentials in this category would be difficult to find and probably so expensive as to be impractical. Furthermore, the small reservoir potentials are extravagant in land inundated per unit of storage.

88. From general appraisals such as those presented in the paragraphs above, it was concluded that the major impoundments offered the optimum potentials for definition of the plan of development of the basin's water resources. However, a plan of development defined solely in terms of major impoundments would not necessarily constitute the optimum plan for all levels of development. Improvements to provide for the needs at the uppermost headwater areas and the intermediate upstream areas that remain unsatisfied by major impoundments, would have to be defined and integrated into the comprehensive plan of development. Also, supplemental programs of particular value in the reaches below the major impoundments seem desirable to further round out the comprehensive nature of the development.

89. Controlled Use of Flood Plains. The impoundment measures discussed above can be used effectively to produce many of the needed goods and services of water resources development. However, it was obvious that their use to completely satisfy these needs would be geographically, hydrologically and economically infeasible. In considering this aspect of the problem attention was directed toward controlled use of flood plains as a supplemental means of producing the needed goods and services, particularly, in the fields of flood control and recreation. Indeed, the controlled use of the flood plains has been advocated by some as the primary means of attaining flood control, but experience has indicated that this is not practical for areas of substantial size such as the Delaware River basin and its principal tributary basins. Comprehensive appraisals of experience in land use regulation 14/ and changes in

14/ Francis C. Murphy, "Regulating Flood Plain Development", Dept. of Geography Research Paper No. 56, University of Chicago, 1958.

flood plain occupance 15/ have recently been made. Also, in recent report to the Congress 16/ the Tennessee Valley Authority described a combined flood plain zoning and urban renewal program designed to alleviate flood damages in the vicinity of Lewisburg, Tennessee.

90. The controlled use of flood plains encompasses such measures as prevention of channel encroachment, zoning to regulate the use of the flood plain, reconstruction of existing structures in the area subject to flooding, adjustments in the occupance of structures in the flood plain, evacuation of the flood plain either on a permanent basis to provide for parks and other flood damage free developments or on a temporary basis by flood warning arrangements, and, finally, combinations of these various measures. Programs to effectively apply these measures must be initiated and administered by local interests. In fact, zoning and similar devices for controlling flood plain development are said to come under the general category of policing powers, delegated by the Constitution to the states and, in turn, usually delegated to counties, township and municipal governments. In the Delaware basin, the power is delegated by the States of New York, New Jersey, Pennsylvania and Delaware to their various subdivisions. New York, New Jersey and Pennsylvania have specific statutes that allow municipalities to incorporate flood zoning provisions in municipal zoning ordinances. In Delaware, the Attorney General's office could find no authority competent to act in the public interest in flood plain zoning. Two states in the Delaware basin - Pennsylvania and New Jersey - have enacted and are enforcing laws that contain channel encroachment provisions.

91. The widespread application of reasonably uniform zoning or other programs to control use of flood plains throughout the Delaware River basin would take on monumental proportions, but would not necessarily be an impossible undertaking. The application of these programs to individual local areas of high residual flood potential seems highly practical under conditions now prevailing. Murphy points out that the lack of basic data is one of the frequently cited problems of planning for flood damage prevention. The compilation of adequate data for this purpose involves field surveys and office computations. In the former are included the detailed topographic surveys and mapping to define channel and flood plain dimensions, elevations of known highwater marks, data on type and extent of flood damages and damage estimates. The

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15/ Gilbert F. White, et.al. "Changes of Urban Occupance of Flood Plains in the United States", Dept. of Geography Research Paper No. 57, University of Chicago, 1958.

16/ TVA, "Program for Reducing the National Flood Damage Potential", Memo to Committee on Public Works, U. S. Senate, 86th Congress, 1st Session, 1958.

office work includes backwater computations to establish flood profiles, estimates of flood discharge and stage frequencies, transfer of flood profiles to recent maps of the area, and compilation of data on stream flow velocities, duration of flooding, rate of rise of flood flows, sharpness of flood crest and rate of flood recession. It is estimated that a complete study of this type for communities of this basin would cost $5,000 and up, each, depending on the size of the community and other factors. Portions of the results of flood plain zoning studies 17/ of the Neshaminy Creek basin are shown on plates Q-4 and Q-5. It should be noted that this particular zoning effort tends to combine channel encroachment features (channel area of high velocity) with flood plain inundation for a flood with 2 percent chance of occurring in any one year. Typical examples of data required for flood plain zoning purposes as prepared by TVA for communities in the Tennessee Valley were discussed in the March-April 1960 issue of The Military Engineer 18/. The features of zoning ordinances were discussed by Murphy and typical samples of such ordinances were included in his research paper. 14/

92. In the course of this investigation a great amount of data, in varying degrees of detail, has been assembled on (a) the extent of flooding, (b) the percent chance of recurrence of flood stages in a range of magnitudes at numerous locations and (c) the type and location of damages attending these flood stages. These data are available for conditions prevailing at the time of survey and for various plans of improvement considered herein. Such data can and will be furnished in useful form to those planning zoning and other types of supplemental programs to ameliorate flood problems in the basin.

93. Some of the factors that led to the use of flood plains for industrial purposes may lead, also, to adverse effects on the economy of the region in the event the industries are restrained in their use of the flood plain. For example, an industry that is a large user of water may be forced to locate on ground above an established flood stage and, thus be penelized in their daily operations by having to lift all of their needed water through an additional vertical distance of, say, 20 feet. Based on an assumed additional head of this magnitude for all self-supplied industrial water from surface sources, it can be shown that the added operating costs to the present industrial water users in

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17/ From studies by Bucks County Planning Commission and data on file in U. S. Army Engineer District, Philadelphia, Department of the Army.

18/ James E. Goddard, "Flood Damage Prevention in the Tennessee Valley", The Military Engineer, March-April 1960, No.52 No. 346.

14/ Ibid.

the Trenton-Philadelphia reach would be in the order of two or three thousand dollars annually. On the other hand, this type of possible adverse effect on the regional economy may be significant in areas and communities with economies less directly associated with large water using industry.

94. The individual localities exercise primary jurisdiction over programs to restrain or control the use of flood plains in their immediate vicinity, and certain of the economic effects of such programs are mostly local in extent; accordingly, it seems proper that decisions with regard to the details of such programs also be subject to close integration of local desires into a broad regional pattern. Local interests may have to decide whether they want recreational or industrial developments on the flood plains in their communities. As an aid to the definition of such programs, areas of substantial local flood damages susceptible to amelioration by controlled use of the flood plains, are shown in table Q-11.

95. Protection of Localized Flood Damage Centers. Where flood control is the sole or dominant need of a basin or locality, levees or flood walls, and channel improvements, are often found to be suitable solutions for the local flood problems. In this investigation where a multiplicity of needs are being considered on a coequal basis, the relative efficiency and economy of local protection measures must be appraised in arriving at decision to appropriate impoundment potentials for short-term uses. As indicated in section II above, the basin is characterized generally by narrow stream valleys that are cluttered with highways, railroads and numerous small communities. Such physical characteristics generally do not permit economic use of levees or flood walls because of the small area protected per unit length of protection measure. A study was made to determine the relative economy of local protection measures at nine localities on the Delaware River below the Tocks Island dam site. Preliminary estimates show that the cost of providing a reasonable degree of local protection by levees at these local areas would be about $35 million. The total flood losses in these areas, if completely eliminated, would justify an expenditure of less than $25 million. Further investigations indicated that local protection measures were economically feasible at some of the individual localities under study. Careful consideration was given to the feasibility of local protection works at Port Jervis, New York. It was found that present levees and flood walls provide reasonable protection against frequest flooding. Protection from infrequent floods of great magnitude would involve expensive rights-of-way, poor foundation conditions requiring extensive treatment against under seepage and internal drainage problems of major proportions. The cost of additional protection measures for this locality cannot be justified at this time. Studies 6/ in connection with this investigation showed local protection measures

6/ Ibid

TABLE Q-11

LOCAL FLOOD DAMAGE CENTERS

Locality	Stream	Area Flooded		Remarks
		Flood	Acres	
Margetville, N.Y.	E.Br. Delaware R.	Nov. 1950	100	a,
Rockland, N.Y.	Beaverkill	Nov. 1950	40	a,b
Roscoe, N.Y.	Willowemoc Cr.	Nov. 1950	65	a,b
Livingston Manor, N.Y.	L. Beaverkill & Willowemoc Cr.	Nov. 1950	40	a,b
South Sterling, Pa.	Wallenpaupack Cr.	Aug. 1955	10	a,c
Newfoundland, Pa.	Wallenpaupack Cr.	Aug. 1955	50	a
Greentown, Pa.	Wallenpaupack Cr.	Aug. 1955	10	b
Tusten Township, N. Y.	Ten Mile River	-	-	a
Milanville, Pa.	Calkins Cr.	-	-	a,c
Liberty, N.Y.	Mongaup R.	-	-	a,b
Port Jervis, N.Y.	Delaware R. & Neversink R.	Aug. 1955	50	b
Claryville, N. Y.	Neversink R.	-	-	a
Wurtsboro, N.Y.	Wilsey Brook	-	-	a,c
Sullivan County, N.Y.	Sheldrake Stream	-	-	a
Westbrookville, N.Y.	Basher Kill	-	-	a
Haven, N.Y.	Basher Kill	-	-	a
Godeffroy, N.Y.	Neversink R.	-	-	a,b
Port Jervis, N.Y.	Hollow Brook	-	-	a
Milford, Pa.	Sawmill Cr.	-	-	a,b
Branchville, N.J.	Culver Cr.	-	-	a
Newton, N. J.	Paulins Kill	Aug. 1955	20	b
Blairstown, N.J.	Paulins Kill	Aug. 1955	70	a
Belvidere, N.J.	Delaware R. & Pequest R.	Aug. 1955	50	a
Easton, Pa.	Delaware R. & Lehigh R.	Aug. 1955	265	b
Phillipsburg, N.J.	Delaware R.	Aug. 1955	180	b
Canadensis, Pa.	Brodhead Cr.	Aug. 1955	40	b
Tannersville, Pa.	Pocono Cr.	Aug. 1955	20	b
Lehighton, Pa.	Lehigh R.	Aug. 1955	35	b
Bowmanstown, Pa.	Lehigh R.	Aug. 1955	15	a
Palmerton, Pa.	Lehigh R.	Aug. 1955	10	a
Slattington, Pa.	Lehigh R.	Aug. 1955	3	b
Walnutport, Pa.	Lehigh R.	Aug. 1955	5	b
Treichler, Pa.	Lehigh R.	Aug. 1955	5	b
Catasqua, Pa.	Lehigh R.	Aug. 1955	25	b
Freemansburg, Pa.	Lehigh R.	Aug. 1955	60	a
Bath, Pa.	Monocacy Cr.	Aug. 1955	15	b
Riegelsville, Pa.	Delaware R.	Aug. 1955	100	b
New Hope, Pa.	Delaware R.	Aug. 1955	80	b
Yardley, Pa.	Delaware R.	Aug. 1955	150	b
Trenton, N.J.	Delaware R.	Aug. 1955	250	b
Hamilton Township, N.J.	Assunpink Cr.	-	-	e
Burlington, N.J.	Delaware R.	Aug. 1955	580	b
Bensalem Township, Pa.	Neshaminy Cr.	-	-	a
Chalfont, Pa.	Neshaminy Cr.	Aug. 1955	55	b
Newportville, Pa.	Neshaminy Cr.	Aug. 1955	60	b
Lumberton, N.J.	Rancocas R.	-	-	a,e
Tamaqua, Pa.	L. Schuylkill R. & Wabash Cr.	Aug. 1955	95	b
Kutztown, Pa.	Sacony Cr.	Aug. 1955	175	b
Shoemakersville, Pa.	Schuylkill R.	-	-	a,b
Reading, Pa.	Schuylkill R.	Aug. 1955	130	b
Birdsboro, Pa.	Schuylkill R.	Aug. 1955	10	a
Pottstown, Pa.	Schuylkill R.	Aug. 1955	250	b
Sellersville, Pa.	Perkiomen Cr.	-	-	a,b
Norristown, Pa.	Stony Cr.	Aug. 1955	85	a,b
Norristown, Pa.	Schuylkill R.	Aug. 1955	40	b
Norristown, Pa.	Saw Mill Run	Aug. 1955	70	b
Whitemarsh, Pa.	Wissahickon Cr.	-	-	b,d
Westville, N.J.	Big Timber Cr.	-	-	a,e
Upper Darby, Pa.	Naylor's Run	-	-	e
Darby, Pa.	Darby Creek	-	-	e
Upland, Pa.	Chester Creek	-	-	e
Pomeroy, Pa. (Chester Co.)	Doe Run Creek	-	-	a
Eddystone, Pa.	Crum Creek	-	-	e
Downingtown, Pa.	E. Br. Brandywine Cr.	Aug. 1955	80	c,d
Coatesville, Pa.	W. Br. Brandywine Cr.	Aug. 1955	90	c,d
Wilmington, Del.	Little Mill Cr.	-	-	d

All areas studied after 1955 flood.

a. Studies based on questionaries and field reconnaissance indicated insufficient flood damages to warrant detailed consideration of costly improvements.

b. Local flood damage problems evaluated in comprehensive survey and taken into account in defining plan of development.

c. Flood protection works provided or proposed by the State.

d. Flood protection works provided or proposed under PL 566 or PL 685.

e. Flood problems arise from local channel encroachments, local encroachment on tidal areas or inadequate local storm drainage.

at eight other localities in the basin to lack economic justification. Studies of some thirty other localities following the 1955 flood showed, also, that protection at none of these was feasible. It was concluded from these investigations that except for those damage centers where local protection measures have been or are now being provided, remaining damage centers in the basin do not present favorable potentials for the economical protection of damage centers by levees, flood walls, or similar local measures.

96. ALTERNATIVE MEASURES AND SUPPLEMENTAL PROGRAMS TO AUGMENT THE SUPPLIES OF USEABLE WATER. As a further assurance that the planning goals relative to the efficient and economic development of the basin's water resources have been met to the greatest practical extent, consideration was given to the place that alternative measures and supplemental programs to augment the supplies of useable waters occupy in the overall planning. In areas of present or projected deficiencies of useable water, attention is usually directed, not only to the impoundment of surface supplies as covered above, but, also, to measures to permit the increased use of existing supplies of water. These latter measures include the exclusion or desalting of saline water, improvement in the quality of available water by diminished pollution load and better use of ground water through programs to control its use and augment its available quantities.

97. Use of Ground Water. In 1955 ground-water resources were used to satisfy 440 mgd or about 15 percent of the water needs (exclusive of cooling water for thermal power) of the basin. Most of the available ground water is in the aquifers of the Coastal Plain areas of New Jersey and Delaware. Ground water in the Appalachian Highland portions of the basin is generally sufficient only to meet the water needs of individual homes, farms and small industries in the rural and suburban areas. Communities depending on ground-water resources in these portions of the basin have experienced water supply problems during drought periods, a notable example being the inadequacies of ground-water supplies at Lansdale, Pennsylvania, in 1957. In projecting gross and net water needs 9/ the use of ground water in the Appalachian Highland portions of the basin were assumed to increase from about 130 mgd in 1955 to 440 mgd at year 2010.

98. In the Delaware River basin the ground-water use has been assumed to increase from 430 mgd in 1955 to about 1,480 mgd at year 2010. The U.S. Geological Survey 19/ has estimated the

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9/ Ibid.

19/ Appendix N, "General Geology and Ground Water", prepared by U. S. Geological Survey, Department of the Interior

unused water resources of the Coastal Plain area at about 800 mgd that are susceptible to economic use. Since this is the major supply of ground water in the region, there can be little doubt that the ground-water resources of the basin are inadequate as a means of satisfying a major portion of the estimated total gross needs of 13,000 mgd at year 2010. In fact, the assumed 11.5 percent of gross water demands to be satisfied from ground water 9/ at year 2010 may represent the use of virtually all ground-water resources presently considered available for economic use. This possibility focuses attention on the need, at an early date, for a basinwide program to rigidly control the magnitude and geographic distribution of the use of ground-water resources and to augment these resources, where the geologic formations permit, by use of artificial ground-water recharge, subsurface storage of surface excesses, and similar measures.

99. Measures to Exclude Salt Water. The proximity of salt water to the general areas of maximum water demands along the lower reaches of the Delaware River and in the vicnity of the estuary led to consideration of measures to change the saline concentrations and otherwise improve the quality of the surface water in those areas. The provision of a salt water barrier across the estuary at about mile 64.6 above the Capes and in the reach between Pea Patch Island and New Castle, Delaware, was found 20/ to be practicable from the viewpoint of engineering but economically infeasible at this time. Such a project would simply move the salinity front in the estuary about 22 miles seaward from its present location in the vicinity of Chester, Pennsylvania, (mile 83 above the Capes). Studies 21/ have indicated that a minimum inflow of 5,500 cfs of fresh water to the estuary would also result in the salinity front moving seaward. In this case the front would move about 12 miles. However, appraisal of the overall effects in this case would require exhaustive studies taking into account sea level changes 22/ along the coast and complications arising from possible changes in the salt water encroachment. Thus, measures to shift the salinity front in the estuary appear to offer little potential at this time as a means of satisfying the needs of the service area in an efficient, economic and adequate manner.

9/ Ibid.
20/ Appendix S, "Salt Water Barrier", prepared by the U. S. Army Engineer District, Philadelphia, Department of the Army.
21/ WES Miscl. Paper No. 2-358.
22/ H. A. Manner, "Sea-Level Changes Along the Coast of the United States in Recent Years". Am. Geophysical Union Trans. V30,1959.

100. Salt Water Conversion. The desalting of saline water was considered as a means of satisfying portions of the water supply needs. Initial investments, maintenance costs and energy requirements for existing processes were found to be so high that there seems little likelihood that saline water conversion would be economically feasible in the Delaware basin in the foreseeable future. The Chairman of the Senate Select Committee on National Water Resources 23/ reported in 1960, "The cost of fresh water produced by the most efficient existing sea water conversion plants is now about $1.75 per 1,000 gallons. It is anticipated that the first two sea water distallation demonstration plants will produce fresh water from the sea for $1.00 or less per 1,000 gallons."

101. Based on cost-yield relationships for existing water supply reservoirs in the basin, the costs of raw water supplies from these surface water impoundments varies from two to four cents per 1,000 gallons for projects yielding 650 mgd and 65 mgd, respectively. Reservoir potentials under consideration in the basin afforded similar low cost vs. yield possibilities and it was clear that saline water conversion does not constitute at this time an economically feasible means of satisfying any part of the water supply needs when compared to development of the water resources of the basin.

102. Improved Water Quality. During possible drought periods in the future, the water withdrawn from surface water sources in the basin used for municipal and industrial purposes and returned to the Delaware River system actually may exceed the quantities of stream flows available. This is possible through repetitive use of the stream flows as they progress from the headwater levels of the basin to the sea. The present and possible future extent of this repetitive use was taken into account in estimating the net water needs 9/ of the various water problem areas of the basin. If each individual use of the basin's water could be accomplished without depreciation of the quality of the water, the extent of repetitive use would be almost unlimited and surface waters required to meet the net needs at dates in the future would be materially reduced thereby. Under these conditions, it could be held that improved and more extensive waste treatment to assure the quality of the returns would serve as an acceptable alternative means of satisfying the water needs of the basin.

23/ Committee Print #26. Saline Water Conversion. Select Committee on National Water Resources, U. S. Senate, 1960.

9/ Ibid.

103. In their appraisal of the present and future quality of the waters of the basin from the headwaters to Trenton, the U. S. Public Health Service found 2/ that the 1957 population of 681,000 for that part of the basin contributed a pollution load equivalent to a population of 143,000. About 341,600 of this tributary population was served by sewer systems and 328,000 were served by facilities providing complete sewage treatment. The installation and expansion of sewage treatment facilities serving populations presently sewered is expected to result in a pollution load in these waters equivalent to a population of 135,000 at year 1962. After 1962 the rise in populations will necessitate the sewering of additional populations which, according to the Public Health Service, will result in pollution loadings to the streams (regardless of the extent of treatment) where none existed in the past. By 1980 the total pollution load discharged to the streams above Trenton will be equivalent to a population of approximately 220,000 and equivalent to a population of approximately 320,000 at year 2010. However, except for occasional local degradation of stream quality, it is expected that little change will occur by 2010 in the overall quality (Average D.O. at 5.0 ppm or more) of these waters.

104. For the waters of the estuary from Trenton to Delaware Bay, the Public Health Service found that the pollution load was equivalent to a population of 4,600,000 people in 1958. Eight principal metropolitan areas in the Trenton-Wilmington reach accounted for 94% of the total municipal pollution load discharged directly to the estuary. The total load to the estuary was distributed 64 and 36 percent to municipal and industrial sources respectively. In projecting the pollution loads a medium condition was assumed wherein the overall removal efficiency for the raw municipal load for the eight principal metropolitan areas was placed at 50 percent. A "best" condition would have placed this removal efficiency at 70 percent. Based on assumed median conditions for both municipal and industrial pollution loads the Public Health Service estimated that the total load discharge to the estuary would be equivalent to a population of 4,600,000 people at year 1965, 5,600,000 people at year 1980, and 7,800,000 people at year 2010. From studies of pollution loading for the period 1950-1957 the Public Health Service concluded that the increased loading for the period ending in 2010 will not materially affect the dissolved oxygen levels (nine year average D.O. of 4.0 ppm at Marcus Hook and minimum average daily D.O. of 0.6 ppm at Marcus Hook) already established.

2/ Ibid.

105. The projections of water quality for the Delaware River and the estuary as described above indicates that the overall quality will remain substantially unchanged in the period to year 2010. For the period to 2010 it is apparent that improved and extended waste treatment cannot be relied upon as a means of improving the waste removal to the extent that the present assured flows in the streams of the basin would satisfy all or a substantial part of the water needs of the basin by simply making possible an increase in the repetitive use of surface water of sustained high quality. It is also apparent that acceptable water qualities in the basin will depend on a continued and vigorously executed program to assure a "median" or "best" condition of removal of the raw pollution load. Such a program must take a high position in the overall development of the water resources of the basin.

106. Conservative Use of Water. The general water use habits of the basin and water service area have generated from a long history of bounteous supplies of high quality waters available to the individual or corporate users for the taking. The exercise of strict water conservation practices possibly could serve to prolong the current era of reasonably adequate water quantities without extensive and costly development projects. The water demand projections in Appendix P show that the earliest need for additional surface water flows would be in the Lehigh water problem area where the base metal industries are the current major users of self-supplied industrial water. Actually, the exact water requirement per ton of steel for the steel industry as a whole varies over a wide range depending on the availability of water and other factors. An average requirement is about 65,000 gallons per ton of steel, yet the Fontana plant in California operates on less than 2-1/2 percent of this average requirement. Sustained and substantial water economies would have to be invoked in the Lehigh problem area to permit any real delay in the development of new water supplies for that problem area.

107. Examples may be cited of plants in the petroleum and paper industries that operate on fractions of the average water requirements per unit of product for those industries. The average requirement for thermal electric generation is about 80 gallons per kilowatt hour but known cases using recycling have reduced this requirement to 1 or 2 gallons per kilowatt hour. Even in the use of domestic water, public water-saving campaigns have been effective in materially reducing the daily water requirements for the duration of critical drought periods. However, persistent and widespread economies in water use cannot be expected voluntarily and even with a vigorous and sustained water saving campaignthe desired results would take a long time. Probably the most effective incentive to recycling and other water conservation measures would derive from increased costs for developing and using the needed supplies of water.

108. Increased repetitive use of water as it flows from the headwater levels of the basin to the sea has been considered as an alternative to developing new water supplies. As indicated above in paragraph 102 the problem of water pollution may act as a deterrent to effective levels of repetitive use of water. Also, the strongly held local preferences in some areas for the development of upland sources for municipal water supplies would probably require an extended reformation program to condition some segments of the public into general acceptance of repetitive use of the waters of the basin. In some parts of the country repetitive use of water is practiced intensively, particularly during drought periods, with no apparent ill effects on the well-being of the inhabitants. Possibly a more acceptable type of repetitive use of water would be the use of treated sewage effluent for specific types of reuse in areas where the surface supplies are predominantly saline. A well known example of this type of reptitive use of water is the case of the Sparrow Point plant of Bethlehem Steel Company in Baltimore, Maryland, where treated effluent from Baltimore's treatment plant is used at an estimated cost of less than 2 cents per thousand gallons. Obviously, this type of direct repetitive use can only be adapted to specific water demands amenable to the use of water of this quality.

109. The practice of conservation in the use of water has much to offer in an area such as the Delaware River basin where projected population and industrial activities foretell dwindling surpluses of raw water. Programs to encourage the acceptance and practice of all possible water conservation measures should be a feature of any plan to develop the water resources of the basin. However, because of their inherent lack of dependable, timely and consistent effectiveness, water conservation programs cannot be used as complete alternatives for more positive measures to augment the supplies of water.

110. ALTERNATIVE MEANS OF SATISFYING NEEDS FOR RECREATION, POWER AND OTHER PRODUCTS. In the paragraphs above, the discussion has been devoted primarily to alternative measures and supplemental programs either to produce the desired water control and augmented supplies of water or to reduce the needs for these products as in the case of flood plain zoning to mitigate future flood problems or conservation in the use of water to lessen the net water demands of the future. In all cases these have to do directly or indirectly with the control and use of water resources. Recreation, hydroelectric generation and water transportation fall in a slightly different group of water resources products. In these cases the end products can be, and usually are, produced without reference to water resources development. However, the development of water resources in such manner as to maximize the output

with minimum investments in productive resources required that all practical alternative means of producing needed goods and services be appraised in the best possible terms regardless of their dependence on water resources or their lack of such dependence. Studies 24/ showed that there is little or no need in the basin at the present time for additional improvements for water borne transportation and alternative means for satisfying such needs are of little interest in this investigation. The alternative means for supplying additional recreation opportunities and electric generation are discussed below.

111. Alternative Means of Augmenting Recreation Opportunities. The studies pertaining to recreation as reported in Appendices I 25/ and W covered in detail the various aspects of alternate means of augmenting the recreation opportunities in the basin. The relative efficiency of water resources developments or alternate public and private recreation facilities to produce needed recreation opportunities must be expressed in terms of days of recreation per unit of facility. For basically different types of recreation developments (commercial amusement park vs. state park) comparisons of their relative efficiency to produce recreation opportunities would be meaningless. Even for similar types of development (reservoir development vs. state park) their relative efficiency would need to be related to, say, units of productive land taken out of production. However, the significance of such a comparison would be questionable because of the effects of such factors as proximity to population centers, accessibility, specific facilities provided, etc., that enter into the estimates of days of recreation anticipated at such developments. While it appears that a reasonable evaluation of the efficiency of water resources developments to provide recreation opportunity is not now feasible, their relative economy to provide recreation opportunity can be readily appraised. As established in Appendix W, the cost of the alternative recreation developments is the basis used for economic appraisals of recreation features of the water resources projects. The recreation potentials at the multi-purpose reservoir projects under consideration in the Delaware River basin show decided economic advantage over practical alternative recreation development.

24/ Appendix E, "Navigation", prepared by the U. S. Army Engineer District, Philadelphia, Department of the Army.
25/ Appendix I, "Recreation Resources", prepared by the National Park Service, Department of the Interior.

112. Alternative Means of Supplementing Power Generation. From the standpoint of efficiency, as used in these general appraisals, hydroelectric power has the inherent characteristics of being ready with minimum delay to meet peak power requirement as opposed to the substantial delay involved in the similar use of conventional thermal power plants. On the other hand, hydropower installations are limited to the geographic locations of feasible sites and the physical and hydraulic limitations peculiar to the sites. The relative economy of hydroelectric installations as compared to conventional thermal-electric installations has been taken into account in the capacity and energy values established by the Federal Power Commission 11/. The studies of hydroelectric power potentials of the basin are reported in Appendix T 26/and the final economic appraisals of economically feasible hydropower installations are given in Appendix V 27/.

113. The expected trend of nuclear power plants as alternatives for conventional or hydroelectric power developments was made the subject of inquiries to the Atomic Energy Commission. That agency advised that it anticipated the nuclear powered electric plants would be base load plants and therefore noncompetitive with hydroelectric plants used for peak power purposes. The opinion was expressed that when nuclear power costs are reduced to the point where they are competitive in a specific area, most of the plants thereafter constructed in such area will be nuclear. The Commission estimated that probably by 1980 and certainly by 2010, nuclear power costs will have been reduced to a level as low or lower than comparable conventional power costs in the Delaware River service area.

114. SUMMARY. From the general appraisals in the paragraphs above it was concluded that major control impoundments are the only practical development with the dimensions and capabilities to physically control excess flood flows, yield the additional flows to meet anticipated demands for supplies of water, and provide for additional water based recreation opportunities to satisfy the demands of an ever increasing population.

11/ Ibid.

26/ Appendix T, "Hydroelectric Power", prepared by the U. S. Army Engineer District, Philadelphia, Department of the Army.

27/ Appendix V, "Benefits and Cost Allocations," prepared by the U. S. Army Engineer District, Philadelphia, Department of the Army.

However, while a plan of improvement based solely on major control impoundments would be effective primarily in the principal water-course areas, it would constitute a sound base for the addition of measures to produce the needed goods and services in the uppermost headwater areas and the intermediate upstream areas. To complete its comprehensiveness the plan of improvement must include the needed programs in controlled use of flood plains, elimination of pollution loads, and conservation in the use of water. The step by step procedures for defining the basic plan of major control impoundments and augmenting it with needed improvements at other levels of development and with supplemental programs are described in detail in the following section of this appendix.

VI ESTABLISHMENT OF THE PLAN OF DEVELOPMENT

115. INTRODUCTION. This section of this appendix reports on the series of successive determinations by discrete screenings used in forming a plan of development. Preliminary considerations to eliminate some of the major impoundment and development potentials that were in the original inventory are reviewed briefly. An analysis to establish an "order of merit" for the projects under consideration is reported, followed by a description of the analysis to establish a "basic plan". Studies to refine the size and use potentials of each element included in the basic plan are described and the measures and supplemental programs to augment the refined basic plan are defined. Finally, studies to establish a logical sequence of development for the elements of the overall plan are described.

116. PRELIMINARY CONSIDERATIONS. The inventory of major impoundment and development potentials in the basin, as described in paragraph 79 above, listed 193 reservoir sites. The preliminary compilation of those sites dated 14 February 1958 contained 185 dam sites. This preliminary list was submitted to cooperating agencies for review and suggestions as to worthwhile additions. From this review and other sources the list was finally expanded to the 193 dam sites referred to above. This list of sites was compiled from a number of more or less independent studies of the water resources of the basin that were made over a period of about 30 years. A review of the locations of the dam sites listed in this inventory indicated an apparent complete independence among those making the studies, with the results that a number of limited reaches on tributaries in the basin were literally salted with dam sites that had been considered in one or more of these studies. On some tributaries the distance between dam sites was less than one mile. There was a total of 38 sites listed on the Delaware River between Hancock, New York and Yardley, Pennsylvania, a distance of 194 miles.

117. In the broad planning studies to define a comprehensive plan of development for the basin, a number of dam sites closely grouped on a tributary represented a single impoundment potential with a choice of dam sites. In such cases a single dam site was selected on the basis of map studies. Where a number of widely scattered dam sites were listed for a tributary with few or no known local problems, the site nearest the mouth of the tributary was generally favored because of the greater size of the drainage area controlled. Maps and profiles were studied to arrive at the most practial sites for further consideration on the Delaware River proper. Preliminary considerations of this type resulted in a list of 70 major impoundment and development potentials, on virtually all tributaries and the main stem, that appeared to warrant more detailed

consideration. These major impoundment and development potentials are listed in Table Q-12 and their locations are shown by index numbers on plate Q-6. The existing Prompton project in the Lackawaxen River basin was subsequently studied for possible modification to provide long-term storage at that site. The location of the Prompton project is indicated, also, on plate Q-6.

118. ORDER OF MERIT OF PROJECTS UNDER CONSIDERATION. The general procedures followed in these planning studies required that the plan for balanced development of the water resources of the basin be defined, basically, in terms of major impounding measures with other types of measures studied as desirable additions to assure an optimum level of development in keeping with the planning goals. The impounding and development potential listed in Table Q-12 includes the major impounding measures from which the plan had to be fashioned. Detailed appraisal of all possible combinations of the elements listed would be an undertaking of considerable dimensions. As a practical means of limiting the number of possible combinations to be considered in detail, an order of merit for the major impounding sites was established for use as a guide in establishing the combinations for detailed study. With such a guide the initial groupings of major impounding units to meet future water control needs at designated dates in the future could be made with some assurance that they would result in balanced water resources development with thrifty investments in productive resources. Also, an order of merit for the sites would identify those sites with such low relative merit that there would be little or no likelihood of their eventual justification. These latter sites were to be avoided in the initial groupings of units into basic plans for further appraisal.

119. The 70 sites listed above include only 50 sites that could be used for major impoundments. The index numbers for these sites in Table Q-12 are marked by asterisks. In this group are included modification of the existing Wallenpaupack project and the Bear Creek project, the latter currently under construction. Since the Sterling and Tobyhanna projects are alternatives for these projects existing or under construction, the latter were omitted from the order of merit study. The remaining 20 sites in the list include for hydroelectric power generation 15 sites on the Delaware River, 2 sites on the lower reaches of the Mongaup River and 3 sites in the Lehigh River basin. The appraisal of these sites involved stream flows as modified by impoundments elsewhere in the basin and other factors unique to the analyses of hydropower potentials. These 20 sites were omitted from the order of merit study in favor of detailed consideration of them in the overall hydroelectric studies as reported in Appendix T. Accordingly, 48 major impoundment sites were included in the order of merit appraisal.

TABLE Q-12

MAJOR IMPOUNDMENT OR DEVELOPMENT SITES

Index No.	Dam Site	Stream	Index No.	Dam Site	Stream
1*	Hawk Mountain	E.Br.Del.R.	36*	Sarapta	Beaver Brook
2*	Cannonsville	W.Br.Del.R.	37*	Pequest	Pequest R.
3*	Equinunk	Equinunk Cr.	38*	Tobyhanna	Lehigh R.
4	Hankins	Delaware R.	39*	Bear Creek	Lehigh R.
5*	Callicoon	Callicoon Cr.	40	Mud Run #1	Mud Run
6	Callicoon	Delaware R.	41	Stony Cr. #2	Stony Cr.
7	Cochecton	Delaware R.	42	Bear Cr. #3	Bear Cr.
8*	Milanville	Calkins Cr.	43*	Mahoning	Mahoning Cr.
9	Skinners Falls	Delaware R.	44*	Beltzville	Pohopoco Cr.
10	Narrowsburg	Delaware R.	45*	Aquashicola	Aquashicola Cr.
11	Tusten	Delaware R.	46*	Trexler	Jordan Cr.
12*	Masthope	Masthope Cr.	47	Chestnut Hill	Delaware R.
13*	Hawley	Middle Cr.	48*	Belfast	Bushkill Cr.
14*	Wallenpaupack	Wallenpaupack C.	49*	Washington	Pohatcong Cr.
15*	Sterling	Wallenpaupack C.	50*	Hackettstown	Musconetcong R.
16*	Lackawaxen	Lackawaxen Cr.	51*	New Hampton	Musconetcong R.
17*	Shohola Falls	Shohola Cr.	52	Holland	Delaware R.
18	Barryville	Delaware R.	53*	Tohickon	Tohickon Cr.
19*	Knights Eddy	Delaware R.	54	Eagle Island	Delaware R.
20	Rio	Mongaup R.	55	Goat Hill	Delaware R.
21	Delaware	Mongaup R.	56*	Crosswicks	Crosswicks Cr.
22	Mongaup	Delaware R.	57*	Newtown	Neshaminy Cr.
23	Hawks Nest	Delaware R.	58*	Birmingham	N.Br.Rancocas Cr.
24	Sparrow Bush	Delaware R.	59*	Eayrestown	S.Br.Rancocas Cr.
25*	Bridgeville	Neversink R.	60*	Moselem	Maiden Cr.
26*	Basherkill Str.	Neversink R.	61*	Bernville	Tulpehocken Cr.
27*	Girard	Bushkill	62*	Monoc	Monacacy Cr
28*	Wallpack Bend	Delaware R.	63*	Fancy Hill	Manatawney Cr.
29*	Flat Brook	Flat Brook	64*	French Creek	French Cr.
30*	Tocks Island	Delaware R.	65*	Spring Mtn.	Perkiomen Cr.
31*	Pine Mtn.	Brodhead Cr.	66*	Evansburg	Skippack Cr.
32*	Bartonsville	Pocono Cr.	67*	Buck Run	Buck Run
33*	McMichael (4a)	McMichael Cr.	68*	New Castle	Brandywine Cr.
34*	Paulina	Paulins Kill	69*	Newark	White Clay Cr.
35	Belvidere	Delaware R.	70*	Christiana	Christina R.

* major impoundment site

120. General Assumptions and Procedures. A number of criteria, assumptions and details of procedure were established for realistic appraisals of the relative order of merit of the impounding potentials under consideration. First, in order that the relative merit of a particular site be truly relative to all other sites the appraisal of the site in question had to be on an individual basis and in accordance with a set of fixed standards and procedures. Thus, the first two criteria adopted for this analysis provided that (1) all sites be appraised, as nearly as practicable, by the same procedures and that (2) each site be appraised individually and as a solitary unit. It should be noted that under these criteria any monetary appraisals of the cost of storage and of the worth of storage for various uses would be merely indices of the relative merit of the sites and would have no relation to benefit-cost ratios as normally understood and used.

121. The sites under consideration are to be construed simply as geographic locations where it is feasible to construct a dam and create a reservoir primarily for the impoundment of water. The cost of developing the various sites would be closely related to the extent of impoundment. Since the approximate costs must be taken into account in establishing the order of merit of the sites, some standard for the extent of impoundment had to be adopted. Basically the comprehensive development of the sites requires (1) that inactive storage be provided to the extent required for the permanent storage of silt to be accumulated during the economic life of the project, (2) that adequate long-term storage be provided for the regulation of low flows with a reasonable period of assumed carryover of the stored waters, and (3) that adequate short-term storage be provided for the temporary impoundment of flood waters from the area above the site. Acceptable planning techniques required that the amount of storage for various purposes at any individual site be established eventually by detailed analysis of the economics of the several uses. However, at this stage of planning such detailed analyses were neither practical nor warranted. Accordingly, the extent of development of the sites was fixed, for purposes of this study, by generalized bases as described in the paragraph below.

122. To arrive at a uniform basis for fixing the extent of development at the various sites, the types of storage required were considered separately. First, it was assumed that the inactive storage would be the minimum required for the accumulation of silt during a 50-year period with the rate of siltation based on the available data on silt load as observed at several points in the basin. Next, the long-term storage required for water supply and low-flow regulation was based on the relations of storage vs. drainage area defined in the water availability study described in Appendix M. Finally, a general relation was established

between drainage area and flood volumes as a basis for estimating the extent of flood control storage required. This relation was defined by actual flood volumes of record floods at gaging stations in the basin and by the volumes of hypothetical floods defined for various points in the basin.

123. The three general relations discussed in the paragraph above were used to establish the extent of development for each site except in cases where physical limitations dictated lesser degrees of development. It was assumed that storage requirements for recreation, fish and wildlife and the myriad of uses associated with low flow regulations would be satisfied by the long-term storage to be provided. In the case of hydropower it was assumed that the provision of facilities for that purpose would be justified by the power revenues and that, pending more detailed economic studies, it could be assumed that long-term storage in the projects would be multiple-use storage with developable power values where economically feasible. Each of the major impounding sites where hydropower appeared feasible were appraised individually for hydropower potentials in a separate study reported in Appendix T. Developments for power alone at 15 sites on the main stem of the Delaware River were deferred for consideration in the detailed power studies and system analyses. As indicated above, these sites were not included in the order of merit appraisals. In the case of recreation and fish and wildlife, standard assumptions of conditions supporting the estimates of public use permitted comparisons of one site with another for relative worth. However, the costs of lands and developments to permit full realization of the potential worth of the projects for these purposes was taken into account either directly or indirectly. In connection with such uses of augmented low flows as pollution abatement, salinity control, improvement of water qualities, water transportation, etc., it was assumed that the high degree of development contemplated for water supply and low flow regulation would, for purposes of this analysis, be adequate for such uses.

124. Cost Indices. With the degree of development or the size of the projects thus established, a standard procedure and set of guides was adopted for preparing preliminary or reconnaissance type estimates of cost for each project. These estimates were based on dam site and reservoir data from the best available maps, conservative assumptions of subsurface conditions based on general geologic intelligence available from various sources, and generalized hydrologic requirements for dam sites in the basin. Based on data from these sources, the reconnaissance estimates included such separate items as concrete dam earth embankment, borrow, spillway, outlet works,

operating equipment, stream diversion during construction, access roads, relocations, real estate, contingencies, engineering and construction supervision. The estimates for the reservoir area included the land costs to an assumed taking line 5 feet above spillway crest, values of buildings within the reservoir area and the cost of relocating roads, railroads, and utilities. The first costs of the projects established by the reconnaissance type of estimates were then converted to approximate annual charges for interest ($2\frac{1}{2}$ percent) and amortization. To these annual charges for each project were added the estimated annual costs for operation and maintenance and the annual cost of developments for recreation at each site as estimated by the Park Service. This process resulted in an approximate total annual cost index for the development of each potential main-stream storage project under study. These indices were entered in the worksheets in terms of dollars but it should be noted that since care was taken within the limits of available data to keep these indices relative to each other, they would be equally useful in establishing the order of merit of the projects if each index were in dimensionless terms.

125. Indices of Worth. In order to insure reasonably acceptable values, the estimates of the worth of the short-term storage for flood control purposes required detailed appraisals in the field of hydrology. The first step in appraising these values required a method of evaluating the effective storage in the individual reservoirs on flood discharges at downstream damage reaches. The data and procedures developed in the flood routing studies permitted an approximate modification of the discharge-frequency relations which, in turn, were converted by routine methods to modified damage frequencies. The latter relations were compared mathematically with the natural damage frequencies to derive an estimate of the worth of the flood control storage in each reservoir with the reservoirs acting as a solitary unit. This procedure was followed for each project in which flood control storage was included and the relative worth of the flood control storage in each site was tabulated for use in establishing the overall indices of worth of the project.

126. The method adopted for appraising the worth of the long-term storage capacities considered in the projects for purposes of water supply and low flow regulation assumed that water for these purposes is worth what it costs to obtain it from the cheapest available source. For a group of reservoirs scattered through the Delaware River Basin, this assumption could lead to an elaborate and extensive study of the costs of obtaining water from several alternate sources such as other reservoirs and ground-water aquifers within and adjacent to the basin. Detailed consideration must be given to this alternative source method and to other possible methods of appraisal in the final analysis of the water problem of the area

but such detailed consideration was deemed unwarranted for purposes of this analysis. As a more practical and expeditious method of arriving at an approximate value considerations were limited to surface water and for this purpose storage was evaluated on the basis of the average cost of obtaining it in the basin. The water value derived in this manner reflected only the average cost of the basic facilities for making surface water available at points in the basin. However, for purposes of this analysis this was considered a reasonable approach because of the abundance and geographic distribution of surface water. In the actual computations, this average value was derived from reconnaissance type estimates for 46 projects in the Delaware River Basin. The average value thus obtained was assumed to be representative of the basic worth of the long-term storage provided for water supply, pollution abatement, enhancement of water qualities, salinity control, water transportation, etc. This could be held to be an oversimplification of some very complicated economic appraisal techniques. However, it does preserve the basic concept of the order of merit in that the values assigned to the storage for water supply and low flow regulation are relative to each other at all of the sites under consideration. Therefore the method adopted here for evaluating worth of storage for these purposes is adequate and practical as a basis for establishing indices of the order of merit of the various projects.

127. The approximate values of recreation and of fish and wildlife propogation at the storage sites were needed to round out the indices of value. The estimates of these values had to be made on the basis of the individual project acting alone. Later refinements must not only take into account the competition of other projects in the plan of development but, particularly in the case of fish and wildlife values, must be net values, taking into account losses of natural values existing prior to development of the projects. For the values needed in the order of merit study, estimates of the worth of each site for public use were obtained from the National Park Service and, for most of the sites, from the Fish & Wildlife Service. In using these estimates it was noted that a very large percentage of the total value for recreation and fish and wildlife was derived from the estimates furnished by the National Park Service. Furthermore, there seemed to be some duplication in the estimates. For these reasons and because estimates by the National Park Service were at hand for all sites, those furnished by that agency were adopted as reasonable values for public use in establishing the indices of these values.

128. Indices of the Relative Order of Merit. Using the indices of cost and the indices of worth established in the manner described above, it is possible to establish indices of the relative order of merit of the individual projects. In view of the nature of the estimates of cost and worth, and the limitations imposed by assumptions and procedures adopted in this analysis, it was considered advisable to reduce this order of merit to its simplest form. This was done by expressing the worth/cost ratio of each project as a fraction of the highest worth/cost ratio identified with any project under consideration. This procedure resulted in an index of one for the project with the highest ratio and lower indices for projects with lesser ratios. By arranging the projects in descending order of these indices an order of merit was established for all of the projects under consideration. While the order of merit was established primarily on the basis of comprehensive development of each site to provide both short-term and long-term storage for several project purposes, the procedures followed also permitted orders of merit for the sites developed only for short-term storage and only for long-term storage. The orders of merit for the three types of development are shown in table Q-13, together with pertinent data on drainage areas and impoundment capacities.

129. As indicated above, the order of merit appraisals were intended as guides to the relative merit of the various impounding potentials under consideration. The individual sites were appraised independently of all other potential sites. Also, the worth of each site was based on the estimated values of the products and effects to be attained from full use of the storage provided and without adjustments to tailor the products and effects to the needs of the area. Thus the relative values for the various sites, while consistent and in proper relation to each other within the concepts of this appraisal, are not to be confused with final appraisals.

130. A relative order of merit was established for each of the major impounding potentials in the basin in this study. However, this does not mean that all of these impounding projects are to be construed as indispensable elements of the ultimate plan for the control and use of the surface waters of the basin. In fact, the order of merit study contains several projects that are alternative to each other and a number of projects of such low relative merit that there seems to be little or no chance of their justification in the foreseeable future. For example, the Knights Eddy, Basher Kill, Wallpack Bend and Tocks Island projects are, in effect, alternatives since no more than one in this group is needed in a balanced plan to meet the basin's needs in the next 50 years. Also, except for their

TABLE Q-13

ORDER OF MERIT FOR MAJOR IMPOUNDING POTENTIALS

Proj. Index No.	Project	Drainage Area Square Miles		Comprehensive Development Long-Term & Short-Term Storage				Development of Long-Term Storage Only				Development of Short-Term Storage Only				Remarks
		Gross	Net (a)	Storage (ac.ft.)	Annual Worth (b) $1000	Annual Cost (b) $1000	Order of Merit	Storage (ac.ft.)	Annual Worth $1000	Annual Cost $1000	Order of Merit	Storage (ac.ft.)	Annual Worth $1000	Annual Cost $1000	Order of Merit	
33	Tohickon	75		62,000	2,764	940	1	33,600	2,763	865	2	29,600	1.0	470	45	
30	Tocks Island	3,827	3,004	635,000	13,475	4,660	2	635,000	15,765	4,660	1	420,000	1,110.0	1,820	2	
51	New Hampton	123		45,000	2,884	1,168	3	45,000	2,884	1,168	7	45,000	63.6	723	28	Capacity limited by geography
67	Buck Run	47		42,000	2,672	1,092	4	22,400	2,642	1,024	4	20,400	30.0	452	35	
70	Christiana	41		40,000	1,938	798	5	40,000	2,000	798	5	17,000	7.5	287	40	
68	New Castle	306		206,000	5,290	2,205	6	112,300	5,210	1,962	3	96,300	80.4	1,005	31	
29	Flat Brook	65		248,000	4,243	1,812	7	22,500	1,842	755	8	26,000	91.0	450	16	
69	Newark	68		57,600	1,940	870	8	30,600	1,930	775	6	27,600	10.0	360	39	
50	Hackettstown	70		51,000	1,917	932	9	26,600	1,853	817	10	28,100	63.6	455	21	
28	Wallpack Bend	3,735	2,912	372,000	9,358	4,700	10	372,000	10,283	4,700	12	372,000	1,000.0	3,315	9	
66	Evansburg	54		47,000	2,711	1,371	11	25,500	2,675	1,199	11	22,500	36.0	611	37	
64	French Creek	47		42,000	1,878	1,020	12	22,400	1,842	881	13	20,400	36.0	447	30	
36	Sarento	33		23,000	1,369	750	13	8,700	1,262	646	16	15,000	76.8	279	11	
25	Bridgeville	160	67	78,000	1,175	728	14	23,000	1,046	449	9	56,000	128.0	410	8	
33	McMichael	63		45,000	1,233	764	15	20,500	1,180	658	18	25,500	52.8	450	26	
17	Shohola Falls	59		42,000	693	452	16	18,500	598	306	15	24,000	94.8	228	7	
44	Beltsville	97	75	61,000	1,223	803	17	25,600	915	680	28	36,600	308.4	593	3	
57	Newtown	150		113,000	3,124	2,187	18	61,200	3,060	1,562	14	53,200	63.6	1,080	38	
1	Hawk Mountain	812	440	403,000	2,983	2,088	19	293,000	3,350	1,875	19	218,000	348.0	1,605	14	
27	Girard	58		42,000	1,489	1,110	20	18,500	1,398	960	23	24,000	91.2	568	20	
38	Tobyhanna	224		86,700	1,255	935	21	86,700	1,255	935	29	-	-	-	47	Short-term storage existing d.s.
65	Spring Mountain	274	206	164,000	3,045	2,300	22	79,600	2,858	1,886	21	86,600	187.0	1,535	25	
46	Trexler	51		44,000	720	547	23	24,400	584	425	25	20,400	136.0	310	6	
61	Bernville	129		112,000	1,433	1,106	24	53,000	1,372	913	22	60,000	61.2	737	29	
34	Paulina	122		95,000	2,203	1,730	25	51,000	2,150	1,194	17	45,000	52.8	828	36	
19	Knights Eddy	2,834	2,011	1,300,000	10,082	8,472	26	1,300,000	13,360	8,472	20	500,000	1,122.0	5,310	15	
63	Fancy Hill	64		54,000	1,329	1,132	27	29,500	1,279	938	27	25,500	50.4	687	43	
37	Pequest	100		75,000	1,334	1,187	28	38,800	1,250	865	24	37,800	83.6	660	24	
26	Basher Kill	3,102	2,186	1,285,000	14,863	13,505	29	1,285,000	15,715	13,505	31	-	-	-	48	Includes diversion from Barryville
49	Washington	13		9,000	343	318	30	2,200	343	248	26	6,900	1.0	221	44	
45	Aquashicola	66		56,000	750	700	31	30,600	490	573	40	26,600	260.0	501	4	
43	Mahoning	538		231,000	2,628	2,500	32	215,000	2,514	2,430	35	17,000	114.0	259	5	Includes diversion from Lehigh R.
13	Hawley	80		59,700	1,221	1,180	33	28,700	1,108	971	32	31,700	113.0	810	22	
62	Monoc	23		22,800	474	467	34	12,200	452	359	30	10,800	21.6	271	33	
15	Sterling	143		50,200	400	395	35	-	-	-	47	50,200	400.0	395	1	Existing long-term storage d.s.
48	Belfast	46		32,000	1,253	1,248	36	13,400	1,183	1,078	33	19,400	69.6	890	34	
60	Moselem	176		135,000	1,648	1,660	37	69,400	1,548	1,437	34	67,400	99.6	1,247	32	
5	Callicoon	111		84,900	837	905	38	44,900	645	715	38	40,900	192.0	650	10	
16	Lackawaxen	595	367	176,000	2,663	3,029	39	176,000	2,070	3,029	42	167,800	302.0	2,872	19	
56	Crosswicks	94		31,600	659	752	40	31,600	659	752	39	31,600	1.0	667	46	Capacity limited by geography
31	Pine Mountain	67		48,000	876	1,044	41	22,000	795	770	36	27,000	80.4	678	27	
32	Bartonville	39		27,000	510	653	42	10,300	430	424	37	17,300	80.4	440	18	
59	Keyrestown	146		15,000	472	659	43	15,000	472	659	41	15,000	10.0	589	41	Capacity limited by geography
58	Birmingham	121		12,200	443	707	44	12,200	443	707	43	12,200	10.0	622	42	Capacity limited by geography
2	Cannonsville	450		185,000	401	826	45	-	-	-	48	185,000	181.0	826	13	Long-term storage existing at site
8	Milanville	46		32,400	259	648	46	13,400	159	443	44	19,400	100.0	507	17	
3	Equinunk	59		42,000	316	973	47	18,500	214	668	45	24,000	102.0	760	23	
12	Masthope	29		20,300	196	610	48	7,300	96	381	46	13,300	100.0	452	12	

(a) Less area above existing reservoirs upstream.
(b) The worth and cost of hydropower potentials of the Hawk Mtn., Knights Eddy, Wallpack Bend, Tocks Island, Lackawaxen, Shohola Falls, Basher Kill, Flat Brook, Tobyhanna and Beltsville sites were considered in studies reported in Appendix T.

local effects, the Equinunk, Gallicoon, Milanville, Masthope, Lackawaxen, Shohola Falls, Bridgeville, Girard and Flat Brook projects are, collectively, an alternate for the Tocks Island project. Also, the 10 or 12 projects at the bottom of the list of comprehensive developments were found to be of such low relative merit as to warrant little or no further consideration.

131. Bearing in mind the peculiarities of the appraisals and the qualifications applicable to the findings, the relative order of merit listings were used as guides to the plans of development to be considered in the next step in the general planning procedures. That step involved the appraisal of specific systems of major impoundments designed to meet estimated water control requirements at specified dates in the future. These systems, as will be explained in subsequent paragraphs, were conceived with a view to incorporating the optimum groupings of major impounding potentials in the basin.

132. SELECTION OF A BASIC PLAN OF MAJOR IMPOUNDING PROJECTS. With the order of merit study and appraisals of basin needs as guides, nine separate plans of basic main stream storage and hydropower projects were formulated. Five of these plans were designed do essentially the same job. However, because of geographic locations, project dimensions and other factors, it was not possible to formulate the plans to do exactly the same job with precisely the same degree of development of the resources.

133. One of the primary assumptions involved in the formulation of these plans was economic in character, namely, that there would be a market for all the goods and services derived from each plan of development. The goods and services referred to here are the types to be derived from water resources development and include flood control, water supply, recreation, fish and game opportunities, water transportation, and low flow regulation. Any one of these general categories may include several distinct types; for example, needs for irrigation water from surface sources are actually water supply problems and are included in that category. Another planning assumption had to do with the treatment of the diversion from the basin by the New York City Board of Water Supply. For this phase of the planning studies, it was assumed that the areas above the Cannonsville, Pepacton, and Neversink Dams will contribute only minimum base yields to the downstream flows in the basin. This assumption was adopted solely in the interest of conservatism to assure ample dimensions for the selected basic plan. Other assumptions conducive to the same end could have been adopted but at the expense of simplicity.

134. <u>Plans Considered.</u> Of the nine plans of basic storage and hydropower projects under consideration here, five (Plans A, B, C, D and E) were formulated with a view to producing, insofar as possible, essentially the same goods and services from development and use of long-term and short-term impoundments. The elements included in these plans were selected in accordance with their relative merit, as determined in the order of merit study, and with the geographic distribution necessary to meet estimated water supply, recreation, and flood control requirements in various tributaries and reaches of the Delaware River. The necessary geographic distribution required that these five plans include elements that were found in the order of merit study to have relatively low merit when compared with other potential sites in the basin.

135. In these five plans, as in most other plans under consideration, the elements were arranged in two phases of construction periods in such a manner that the elements of phase I (one) would provide substantial relief from existing flood losses and meet requirements for supplies of water to the year 1980. The elements of phases I and II were designed to meet the water supply needs to the year 2010. The estimates of water supply used in this case were early estimates that were subsequently refined and modified. However, it should be noted that changes in the estimates of water supply demands affect only the probable timing of the construction of the various elements of the plans. The basic composition of these plans is not sensitive to such changes. In later studies the two-phase timing arrangement was abandoned in favor of more accurate fixing of construction times and sequences for the measures included in the plan of development.

136. The active storage capacities for short-term and long-term water impoundments (for all purposes including water supplies for domestic, industrial and rural purposes, and for low flow regulation) were based on empirical relations of flood volume vs. drainage area and the generalized storage-yield relationships prepared during early phases of the hydrology studies reported in Appendix M. Where warranted by the sustained flows to be anticipated from the storage projects in the plan, run-of-river hydropower projects were included.

137. The five initial plans (Plans A, B, C, D and E) were presented to an informal economics work group composed of representatives of the Federal Power Commission, the Public Health Service, the National Park Service, the Department of Agriculture and the Fish and Wildlife Service. A Corps of Engineers' representative was the chairman of this group. Members of the work group were invited to submit additional plans and/or modifications and

adjustments for consideration and appraisal. This resulted in the addition of Plan "F" suggested by the Federal Power Commission representatives with a view to maximizing hydropower development; Plan "G" suggested by the National Park Service representative and directed toward recreation development; and Plan "H" suggested by the Public Health Service representative and designed to provide optimum water supply and low flow regulation. Subsequently, a plan "K" was added at a later date at the request of representatives of the Federal Power Commission. This latest plan included only elements suggested for Phase I development and was composed primarily of potential pumped-storage hydropower projects with added storage provisions as necessary for flood control and water supply. It should be noted that plans F, G, H and K were not comprehensively designed to assure a balanced plan of development of the water resources and, therefore, are useful primarily in considering modifications of the other plans. The elements, and their storage dimensions, of phase I of the plans under consideration are shown in table Q-14 and of phase II are shown in table Q-15.

138. Appraisal of Products of the Various Plans. In arriving at the best balanced plan for water resources development to insure optimum availability of surface water for every use of water, the first step was the evaluations of the goods and services produced by the several plans under consideration. Such evaluation had to be consistent not only from one plan to the next, but also for the various types of goods and services. This latter requirement led to clarifying assumptions relative to the methods and applicable point of evaluation. For example, the unit of measure had to be defined. This was done by simply assuming that the current dollar value of the needs and services would serve as an adequate unit of measure for a comparitive study of the plans of development. Also, the values of the goods and services were based on their monetary values at the point of production. This made estimates of values to the ultimate consumer unnecessary.

139. Attending the evaluations of the various types of products were certain considerations and problems unique to specific goods and services as explained in the following subparagraphs.

a. The evaluation of the flood control features included in the plans followed established procedures wherein the effects of the elements of the plans on damage-frequency relations for downstream reaches are determined by detailed hydraulic studies to permit a monetary evaluation of the average annual values attributable to those features.

TABLE Q-14

ELEMENTS OF PHASE I OF PLANS A, B, C, D, E, F, G, H AND K

Storage in 1000 acre feet

Project	Gross Drainage Area (sq.mi.)	PLAN A Long Term	PLAN A Short Term	PLAN A Total	PLAN B Long Term	PLAN B Short Term	PLAN B Total	PLAN C Long Term	PLAN C Short Term	PLAN C Total
Hawk Mountain	812.				293.0	112.0	405.0			
Hawkins	1,645.				3.5	-	3.5			
Callicoon	1,709.				13.0	-	13.0			
Skinners Falls	1,901.				1.2	-	1.2			
Tusten	1,978.				3.0	-	3.0			
Sterling	143.	1.5	49.0	50.5	1.5	49.0	50.5	1.5	49.0	50.5
Lackawaxen	595.									
Shohola Falls	59.									
Hawks Nest	3,046.				10.0	-	10.0			
Basher Kill	326.									
Girard	58.									
Wallpack Bend	3,735.									
Flat Brook	65.									
Tocks Island	3,827.	335.0	300.0	635.0				335.0	300.0	635.0
McMichaels	63.				20.5	21.0	41.5			
Paulins	122.									
Belvidere	4,365.	31.0	-	31.0				31.0	-	31.0
Pequest	100.									
Chestnut Hill	4,640.	11.0	-	11.0				11.0	-	11.0
Tobyhanna	224.	87.0	-	87.0	87.0	-	87.0			
Mud Run #1	32.	28.5	-	28.5	28.5	-	28.5			
Stony Creek #2	6.	8.0	-	8.0	8.0	-	8.0			
Bear Creek #3	4.	12.6	-	12.6	12.6	-	12.6			
Mahoning	(a) 538.							217.5	-	217.5
Baltsville	97.									
Aquashicola	66.							31.0	22.0	53.0
Trexler	51.							24.8	17.0	41.8
Hackettstown	70.									
New Hampton	123.									
Holland	6,357.	53.0	-	53.0				53.0	-	53.0
Tohickon	75.				34.5	-	34.5			
Eagle Island	6,627.	20.7	-	20.7				20.7	-	20.7
Goat Hill	6,692.	4.7	-	4.7				4.7	-	4.7
Yardley	6,740.									
Crosswicks	94.									
Newtown	150.									
Bernville	129.	53.0	41.0	94.0	53.0	41.0	94.0	53.0	41.0	94.0
French Creek	47.									
Evansburg	54.									
Buck Run	47									

Project	PLAN D Long Term	PLAN D Short Term	PLAN D Total	PLAN E Long Term	PLAN E Short Term	PLAN E Total	PLAN F Long Term	PLAN F Short Term	PLAN F Total
Hawk Mountain				293.0	112.0	405.0			
Hawkins				3.5	-	3.5			
Callicoon				13.0	-	13.0			
Skinners Falls				1.2	-	1.2			
Tusten				3.0	-	3.0			
Sterling	1.5	49.0	50.5	1.5	49.0	50.5			
Lackawaxen							63.0	80.0	143.0
Shohola Falls	20.0	20.0	40.0						
Hawks Nest				10.0	-	10.0			
Basher Kill									
Girard	19.0	20.0	39.0						
Wallpack Bend							120.0	252.0	372.0
Flat Brook									
Tocks Island									
McMichaels	20.5	21.0	41.5	20.5	21.0	41.5			
Paulins	54.0	-	54.0						
Belvidere							31.0	-	31.0
Pequest	41.0	-	41.0						
Chestnut Hill							11.0	-	11.0
Tobyhanna	87.0	-	87.0	87.0	-	87.0	142.0	-	142.0
Mud Run #1	28.5	-	28.5	28.5	-	28.5	28.5	-	28.5
Stony Creek #2	8.0	-	8.0	8.0	-	8.0	8.0	-	8.0
Bear Creek #3	12.6	-	12.6	12.6	-	12.6	12.6	-	12.6
Mahoning									
Baltsville									
Aquashicola									
Trexler									
Hackettstown	24.0	-	24.0						
New Hampton	42.0	-	42.0						
Holland							53.0	-	53.0
Tohickon	34.5	-	34.5	34.5	-	34.5			
Eagle Island							20.7	-	20.7
Goat Hill							4.7	-	4.7
Yardley							5.0	-	5.0
Crosswicks									
Newtown	62.0	-	62.0	62.0	-	62.0			
Bernville	53.0	41.0	94.0	53.0	41.0	94.0	53.0	41.0	94.0
French Creek	23.3	15.7	39.0	23.0	15.7	39.0			
Evansburg	26.5	18.5	45.0	26.5	18.5	45.0			
Buck Run									

Project	PLAN G Long Term	PLAN G Short Term	PLAN G Total	PLAN H Long Term	PLAN H Short Term	PLAN H Total	PLAN K Long Term	PLAN K Short Term	PLAN K Total
Hawk Mountain									
Hawkins									
Callicoon									
Skinners Falls									
Tusten									
Sterling	1.5	49.0	50.5	1.5	49.0	50.5			
Lackawaxen									
Shohola Falls							20.0	20.0	40.0
Hawks Nest									
Basher Kill							600.0	100.0	700.0
Girard									
Wallpack Bend	162.0	210.0	372.0						
Flat Brook	52.0	-	52.0				280.0	20.0	300.0
Tocks Island				335.0	300.0	635.0	335.0	300.0	635.0
McMichaels				20.5	21.0	41.5			
Paulins									
Belvidere	31.0	-	31.0	31.0	-	31.0			
Pequest									
Chestnut Hill	11.0	-	11.0	11.0	-	11.0			
Tobyhanna				87.0	-	87.0	142.0	-	142.0
Mud Run #1				28.5	-	28.5	28.5	-	28.5
Stony Creek #2				8.0	-	8.0			
Bear Creek #3				12.6	-	12.6	12.6	-	12.6
Mahoning	217.5	-	217.5	217.5	-	217.5			
Baltsville							26.3	31.0	57.3
Aquashicola				31.0	22.0	53.0			
Trexler				24.8	17.0	41.8			
Hackettstown	24.0	-	24.0						
New Hampton	42.0	-	42.0						
Holland	53.0	-	53.0	53.0	-	53.0			
Tohickon	34.5	-	34.5	34.5	-	34.5			
Eagle Island	20.7	-	20.7	20.7	-	20.7			
Goat Hill	4.7	-	4.7	4.7	-	4.7			
Yardley									
Crosswicks	31.6	-	31.6						
Newtown	62.0	-	62.0	62.0	-	62.0			
Bernville	53.0	41.0	94.0	53.0	41.0	94.0	53.0	41.0	94.0
French Creek				23.3	15.7	39.0			
Evansburg				26.5	18.5	65.0			
Buck Run				23.0	-	23.0			

(a) 37 sq. mi. on Mahoning Cr. and 501 sq. mi. diversion from Lehigh River

TABLE Q-15

ELEMENTS OF PHASE II OF PLANS A, B, C, D, E, F, G AND H

Project	Gross Drainage Area (sq.mi.)	PLAN A Storage 1000 acre feet			PLAN B Storage 1000 acre feet			PLAN C Storage 1000 acre feet			PLAN D Storage 1000 acre feet			PLAN E Storage 1000 acre feet			PLAN F Storage 1000 acre feet			PLAN G Storage 1000 acre feet			PLAN H Storage 1000 acre feet		
		Long Term	Short Term	Total	Long Term	Short Term	Total	Long Term	Short Term	Total	Long Term	Short Term	Total	Long Term	Short Term	Total	Long Term	Short Term	Total	Long Term	Short Term	Total	Long Term	Short Term	Total
Livingston Manor	63.																			17.8	13.7	31.5			
Craigie Clair	84.																			22.0	-	22.0			
Hawk Mountain	812.	293.0	-	293.0				293.0	-	293.0													293.0	112.0	405.0
Hankins	1,645.	3.5	-	3.5				3.5	-	3.5													3.5	-	3.5
Callicoon	1,709.	13.0	-	13.0				13.0	-	13.0													13.0	-	13.0
Skinners Falls	1,901.	1.2	-	1.2				1.2	-	1.2													1.2	-	1.2
Tusten	1,978.	3.0	-	3.0				3.0	-	3.0													3.0	-	3.0
Shohola Falls	59.																			20.0	20.0	40.0			
Knights Eddy	2,834.										1,300.0	270.0	1,570.0												
Hawks Nest	3,046.	10.0	-	10.0				10.0	-	10.0															
Basher Kill	326.													648.0	-	648.0	608.0	-	608.0	608.0	-	608.0			
Girard	58.																			19.0	20.0	39.0			
Wallpack Bend	3,735.										372.0	-	372.0												
Tocks Island	3,827.				335.0	300.0	635.0							335.0	300.0	635.0									
Paulina	122.	54.0	-	54.0	54.0	-	54.0	54.0	-	54.0							54.0	-	54.0	54.0	-	54.0			
Belvidere	4,365.				31.0	-	31.0				31.0	-	31.0	31.0	-	31.0					-				
Sarepta	33.																			9.0	-	9.0			
Pequest	100.	41.0	-	41.0	41.0	-	41.0	41.0	-	41.0							41.0	-	41.0	41.0	-	41.0			
Chestnut Hill	4,640.				11.0	-	11.0				11.0	-	11.0	11.0	-	11.0									
Mud Run #1	32.																			28.5	-	28.5			
Beltsville	97.	26.3	31.0	57.3	26.3	31.0	57.3				26.3	31.0	57.3	26.3	31.0	57.3	26.3	31.0	57.3	26.3	31.0	57.3	26.3	31.0	57.3
Aquashicola	66.	31.0	22.0	53.0	31.0	22.0	53.0				31.0	22.0	53.0	31.0	22.0	53.0									
Trexler	51.	24.8	17.0	41.8	24.8	17.0	41.8				24.8	17.0	41.8	24.8	17.0	41.8				24.8	17.0	41.8			
Hackettstown	70.	24.0	-	24.0																			24.0	-	24.0
New Hampton	123.	42.0	-	42.0	42.0	-	42.0	42.0	-	42.0							42.0	-	42.0				42.0	-	42.0
Holland	6,357.				53.0	-	53.0				53.0	-	53.0	53.0	-	53.0									
Tohickon	75.																36.5	-	34.5						
Eagle Island	6,627.				20.7	-	20.7				20.7	-	20.7	20.7	-	20.7									
Coat Hill	6,692.				4.7	-	4.7				4.7	-	4.7	4.7	-	4.7									
Moselem	176.	70.0	55.0	125.0	70.0	55.0	125.0	70.0	55.0	125.0	70.0	55.0	125.0	70.0	55.0	125.0	70.0	55.0	125.0	70.0	55.0	125.0	70.0	55.0	125.0
French Creek	47.																			23.3	15.7	39.0			
Evansburg	54.																			26.5	18.5	45.0			
Buck Run	47.																			23.0	-	23.0			
Newark	68.	31.0	-	31.0	31.0	-	31.0	31.0	-	31.0	31.0	-	31.0	31.0	-	31.0	31.0	-	31.0	31.0	-	31.0	31.0	-	31.0
Christiana	41.	37.0	-	37.0	37.0	-	37.0	37.0	-	37.0	37.0	-	37.0	37.0	-	37.0	37.0	-	37.0	37.0	-	37.0	37.0	-	37.0

b. Water supply values were based on the assumption that this type of product is worth the cost of obtaining it from the most inexpensive alternative source. As a matter of expediency, it was further assumed that the mean cost of providing storage at all potential storage elements would constitute a reasonable value for use in estimating the at-the-site worth of the water supply goods and services. While this latter estimate was in terms of cost per acre-foot of storage it could be readily converted through use of established storage yield relations, to cost per unit of net increase in water yield. The net increase in water yields was the actual goods to be obtained from the provision of water supply storage in the plans.

c. The evaluation of the potential public recreation type of goods and services inherent in these plans was based upon estimations, made by the National Park Service, of the annual number of visitor-days use expected at each project. Two levels of developing the recreation potential were considered; one, a designated maximum level for those projects for which one million or more visitors per year might be expected and a basic facilities level for which an attendance of less than this would be expected. This basic concept provided the means for comparing the recreation goods and services from the several plans under consideration. For purposes of these comparisons it was agreed that the maximum level of development would yield a maximum value of recreation per visitor-day and that as the scale of development is reduced, the value would decrease proportionately. In both cases the values used were at-site values. It should be noted that the method employed indicates the potential recreation goods and services inherent in each project as reflected by such factors as nearness to population centers, the income composition of the population, the degree of urbanization of the population and the basic attractiveness of the particular site. The method also provides a basis for comparing the separate costs for producing these values in such variable factors as the number of acres required to satisfy the definition of maximum development and the estimated cost per acre of securing such land for this purpose. It must be borne in mind that in developing plans for recreation as a part of the selected plan these evaluations of recreation goods and services will be replaced with cost and benefit analyses based on actual at-site recreation plans.

d. The appraisal of the fish and game type of goods and services inherent in these plans was furnished by the Fish and Wildlife Service. It is the approximate value that could be credited to the plan for the fish and wildlife expected to occur once the project is in place with no special features for development of the fish and wildlife potential. The Service also furnished estimates, on a replacement basis, of approximate separate costs

of the fish and game resources to be lost because of the projects. It was anticipated that the fish and wildlife agencies would provide later all of the details for such special features as would be required for the selected plan of improvement. Such special features were omitted from considerations to select a basic plan.

e. The Federal Power Commission furnished the basic capacity and energy values used in evaluating the hydropower potentials of the various plans. These values followed established patterns wherein the least cost, including taxes, of producing the electrical energy at the site was used in arriving at the capacity values. The energy values were based on incremental fuel costs.

f. The value of pollution abatement and raw water improvement to be derived from the various plans, ordinarily, would be based on the least cost of obtaining these goods and services from such principal alternative sources as secondary sewage treatment and added treatment of raw water at the point of intake. However, the Public Health Service when consulted in connection with these appraisals pointed out that in at least one state bordering the Delaware River secondary sewage treatment had already been adopted as the standard for future sewage treatment facilities. Under these circumstances it was agreed that any appraisals based on sewage or raw water treatment costs and applicable to a 50-year period in the future would warrant detailed consideration prior to their use in the analysis of water resources development projects in the Delaware River basin. Accordingly, it was decided to forego these appraisals at this stage of the study.

g. The goods and services from the potential use of the water resources of the basin for transportation purposes is best measured by the savings anticipated from the movement of commodities by water. In the Delaware River basin the water transportation potentials have in large part already been exploited or are currently in the midst of additional development. The savings foreseeable at this time from still further development of this type of goods and services would be small and were foregone in the analyses and studies made to select a basic plan for development of the water resources. However, it was recognized that future provision of a cross-Jersey canal or increased channel dimensions on the Delaware River below Trenton may require the development of storage in the basin to provide the additional fresh water supplies which might be needed in connection with these improvements. These water supplies would be charged against the improvements concerned and evaluated in accordance with procedures applicable to the improvements.

140. <u>The Basic Plan of Development</u>. If the various plans under consideration were so constituted that each would produce exactly the same products on the basis of the appraisals discussed above, the identification of the optimum plan would be simple. It would be that plan that could be expected to yield a balanced production of water resources products and services adequate to satisfy the anticipated needs thereof with the least investment of water resources and funds. As was noted earlier, however, the geographic distribution of the worthwhile storage potentials, the wide range in project dimensions and the basic or dominant uses that governed the formulation of some of the plans, all militate against a strict comparison of the plans. Also, the place of pumped-storage hydropower projects in this overall analyses of comparative schemes was fraught with complexities. For example, this type of project can be developed only at sites with favorable physical features yet these sites may be the less desirable ones from the standpoint of the production of such other goods and services as flood control, water supply and recreation. Furthermore, the very nature of the pumped-storage projects required that deliberate and learned consideration be given to the size and cost of reversible units and other factors unique to that type of development. Thus while plan "K" designed to provide pumped-storage type of hydropower developments, was considered in the selection of a basic plan for the basin, it was apparent that pumped-storage potentials would have to be analyzed separately as adjuncts to or replacements for elements of a basic plan of development in order to bring the balanced production of goods and services to the optimum.

141. As a guide to the selection of the basic plan, the products and effects to be expected from the development of the basin's water resources by the several plans under consideration were measured in monetary terms. These values are listed by phases for each plan in table Q-16 together with estimates of the cost of production for each plan. It should be noted that the values and costs under the headings STORAGE represent joint values and those listed under the headings RECREATION, FISH & WILDLIFE and HYDROPOWER represent specific values and costs. Furthermore, these values and costs were computed on the basis of systems, and the products thereof, without any attempt to establish sequences of construction. Also, they were based on the assumption that a market will exist for all products throughout the economic life of the projects. The hydropower values and costs were based on the assumed development of hydroelectric power at each site with known power potentials included in the various plans.

TABLE Q-16

VALUES OF PRODUCTS AND COSTS OF THEIR PRODUCTION FOR THE PLANS UNDER CONSIDERATION

PLAN	ANNUAL VALUE OF PRODUCTS - $1,000,000 Storage (1)	Recreation (2)	Fish and Wildlife (3)	Hydro-power (4)	Total (5)	ANNUAL COST OF PRODUCTION - $1,000,000 Specific Costs Storage (6)	Recreation (7)	Fish and Wildlife (8)	Hydro-power (9)	Total (10)	Net Excess (5)-(10)
					PHASE I						
A	6.2	8.8	.4	9.9	25.3	5.2	5.9	.6	14.0	25.7	- 0.4
B	5.9	3.2	.3	6.0	15.4	5.5	2.1	.3	11.5	19.6	- 4.2
C	8.4	8.6	.4	7.2	24.6	8.2	5.8	.6	9.1	23.7	+ 0.9
D	5.7	11.7	.2	3.1	20.7	9.4	10.7	.8	5.5	26.4	- 5.7
E	7.0	9.8	.3	6.0	23.1	7.9	6.2	.7	11.5	26.3	- 3.2
F	5.2	8.8	.03	9.0	23.0	8.2	5.9	.5	14.0	28.6	- 5.6
G	7.7	20.1	.4	5.2	33.4	11.8	13.5	.8	7.6	33.7	- 0.3
H	11.2	20.4	.5	10.5	42.6	12.8	13.4	1.1	14.5	41.8	+ 0.8
K	10.9	10.3	.2	33.1	54.5	20.1	6.9	.7	16.6	44.3	+10.2
					PHASE II						
A	7.3	9.5	.3	5.0	22.1	8.9	6.1	.7	7.6	23.3	- 1.2
B	8.1	16.0	.4	8.6	33.1	9.6	10.5	.8	10.0	30.9	+ 2.2
C	6.2	7.8	.3	5.1	19.4	7.0	5.0	.6	7.8	20.4	- 1.0
D	19.9	11.9	.5	19.4	51.7	22.9	7.9	1.0	14.2	46.0	+ 5.7
E	13.4	9.7	.5	11.5	35.1	12.9	8.0	.8	12.4	34.1	+ 1.0
F	9.8	10.2	.5	3.4	23.9	11.1	6.6	.6	2.6	20.9	+ 3.0
G	11.3	12.8	.2	4.4	28.7	16.7	8.2	.8	3.3	29.0	- 0.3
H	5.7	7.6	.2	4.5	18.0	6.4	4.8	.5	6.7	18.4	- 0.4
					PHASE I + II						
A	13.5	18.3	.7	14.9	47.4	14.1	12.0	1.3	21.6	49.0	- 1.6
B	14.0	19.2	.7	14.6	48.5	15.1	12.6	1.3	21.5	50.5	- 2.9
C	14.6	16.4	.7	12.3	44.0	15.2	10.8	1.2	16.9	44.1	- 0.1
D	25.6	23.6	.7	22.4	72.4	32.3	18.6	1.8	19.7	72.4	0.0
E	20.4	19.5	.8	17.5	58.2	20.8	14.2	1.5	23.9	60.4	- 2.2
F	15.0	19.0	.5	12.4	46.9	19.3	12.5	1.1	16.6	49.5	- 2.6
G	19.0	32.9	.6	9.6	62.1	28.5	21.7	1.6	10.9	62.7	- 0.7
H	16.9	28.0	.7	15.0	60.6	19.2	18.2	1.6	21.2	60.2	+ 0.4

142. The monetary values of the products and the costs of their production as defined above served as the basis for selecting from the several plans under consideration, a single basic plan to produce, in a balanced manner, the needed goods and services with the least investment of water resources and funds. Bearing in mind the nature of the monetary appraisals and peculiarities arising from assumptions used in the appraisals, the selection of the basic plan actually was based on an elementary type of optimized net return for the plans under consideration. The monetary values and costs for phase I of the plans under consideration indicated that the hydropower costs were so much greater than the returns that there seemed to be little likelihood of the widespread economic development of hydropower in connection with any plan except plan K. Accordingly, the approximate net excesses of values over joint and specific costs were determined for the phase I developments without power facilities. These data showed that, on the basis of the approximate net excesses,the choice of the initial phase of the basic plan without power lay between plan A and plan H. Further considerations of the relative costs of production of these two plans indicated that plan H involved either (a) possible overproduction, (b) production at expensive sites or (c) a combination of overproduction and expensive sites. These considerations led to the selection of plan A as the initial phase of the basic plan because of its relative economy in terms of investments in water resources and funds. Also, the excess net values of plan K which had been designed with a view to maximizing the production of hydroelectric power required that those elements in plan K but not included in plan A be retained in the basic plan. The initial phase of the basic plan thus defined included the following major impounding projects:

Sterling	Tocks Island
Shohola Falls	Tobyhanna
Basher Kill	Beltzville
Flat Brook	Bernville

143. It was recognized that the inclusion of the Shohola Falls, Basher Kill, Flat Brook and Beltzville projects in the initial phase of the basic plan would result in excessive capabilities to produce supplies of raw water. However, because of their potentials as pumped-storage developments, these sites were retained in the basic plan to allow more detailed appraisals of that type of development as a basis for integrating them into the detailed optimization studies to follow. The hydropower studies made subsequent to the selection of the basic plan and reported in Appendix T showed that none of these pumped-storage power projects could be economically developed at this time.

144. The composition of phases I and II of the various plans under consideration was such that major impounding potentials could be included in either phase of a specific plan. Under these conditions the comparison of complete plans (both phases) seemed desirable. However, the modification of the initial phase of plan A to retain the power potentials of plan K foretold the possibility of modifying the selected second phase to retain, say, recreation potentials of a rejected plan. The comparison of the second phases of the various plans required that the detailed values for phase I plus phase II projects and for phase II projects only be considered. From these it was found that on the basis of the net values in excess of costs plans A and H again offered the optimum potentials. It should be noted that except for the composition of each phase there was a great deal of similarity between plans A and H when all elements were considered. The major differences in the two plans on this basis was that, in addition to the major impounding projects of plan A, excepting the Paulina and Pequest projects, plan H included seven additional impounding projects in various parts of the basin. To satisfy the general planning requirements that the plan of development be capable of meeting the needs in a balanced manner and with minimum investment in water resources and funds, the second phase of the basic plan was defined by the phase II elements of plan A plus four of the seven additional projects of plan H mentioned above. Thus the second phase of the basic plan including the following major impounding projects:

Hawk Mountain	Tohickon
Paulina	Newtown
Pequest	Moselem
Beltzville	French Creek
Aquashicola	Evansburg
Trexler	Newark
Hackettstown	Christiana
New Hampton	

145. During considerations to define the basic plan it was realized that the exclusion of apparent high merit sites from the basic plan would be questioned. Such results would be inevitable in the definition of a balanced plan for the optimum development of the water resources of any sizeable basin with complex regional economy as encountered in the Delaware River basin and its water service area. As explained above, the required geographic distribution, system operations, economics of size, appraisal limitations, all contribute to such results. The situation can be attributed generally to fundamental difficulties inherent in a unit cost type study such as the "order of merit" study. Also involved here were the several independent local watershed studies to establish subbasin plans to cope with local needs. While these plans when completed would be integrated into the overall plan for the entire

basin, it was necessary to assume in the selection of the basic plan that active local studies would consider all high merit potentials in the subbasins under study. At least projects of apparent high merit would lose most of their luster if rejected in local planning efforts. On the other hand, the Basher Kill and Knights Eddy projects had sufficient merit to warrant their further consideration as separate alternates for groups of smaller projects in the basic plan or their preservation for future development after the year 2010. The Basher Kill project as indicated above was retained in the initial phase of the basic plan. The Knights Eddy project was retained in the second phase of the basic plan but subsequent studies showed that because of the high cost of railroad relocations to be encountered in fully developing the site it lacked economic feasibility at this time. The locations of the elements of the basic plan are shown on plate Q-7.

146. The definition of the basic plan as described above constituted one of the series of discrete screening leading to a balanced plan for development of the water resources of the basin. Further steps in the overall planning procedures were confined to the various elements of the basic plan or specific alternatives for these elements and to additions to or deletions from the basic plan. The next step in the planning procedures was to determine the scale of development for each major impounding project as described in the paragraphs below.

147. Adjustments to the Basic Plan. In the preceding evaluations 22 major control impoundment sites were selected as the nucleus for the proposed plan of development. That selection, based on initial monetary appraisals of generalized storage allocations, was found to produce a basic pattern of water resource products with the least investment in the available productive resources. Refined water supply and demand studies and hydropower analyses completed subsequent to the selection of the basic plan led to some revisions and interpretations of that plan. As indicated above, the power studies showed that the Shohola Falls, Knights Eddy, and Basher Kill projects were not economically attractive at this time from the viewpoint of hydropower values and costs. Similar finds were made with regard to the ten projects proposed in plan A primarily for hydropower development on the Delaware River below Hancock and below the Tocks Island dam site. It was found also that the development of hydropower in connection with the development of Tobyhanna project lacked economic feasibility at this time.

148. The refined water supply and demand studies showed that the elements included in the basic plan, even without the Shohola Falls, Knights Eddy and Basher Kill projects, would overproduce the supplies of water required to meet the demands. Since the planning principles being followed assumed a market for all products of

the water resources development, the apparent overproduction of water supplies would be without value during the period to 2010. Based on the knowledge of the values and costs of such other products and services as flood control and recreation it was found that the basic plan could be tailored to best meet the balanced demands for the products under consideration by initial development of the Paulina, Pequest, Hackettstown, New Hampton, Tohickon, Newtown, French Creek and Evansburg sites for recreation. This arrangement had the added advantage of assuring the availability of the storage potentials at these sites when their development for water supply purposes is indicated. It should be noted that these assurances are actually of considerable value to the future economy of the basin and while these benefits are not included as features of the recreation developments at these sites they nevertheless will be substantial and real.

149. The Sterling project, when considered in series with the Tocks Island project was found to lack economic justification for flood control purposes and was dropped from further consideration in this survey. Furthermore, it should be noted that when the Tobyhanna project, considered in series with the existing Bear Creek project, is limited primarily to water supply and recreation developments (by the omission of hydropower) it fails to compete economically with an alternative proposal for the additional development of the products at the existing Bear Creek flood control project immediately downstream. Accordingly, the Tobyhanna project was dropped from further consideration and a project to revise the present Bear Creek development added in its stead. Also, because of its extreme economy, a project to revise the present flood control and recreation development at the Prompton dam and reservoir in the Lackawaxen River basin to include long-term storage for water supply purposes was added to the basic plan. Finally, the Blue Marsh project on Tulpehocken Creek in the Schuylkill River basin was substituted for the Bernville project, immediately upstream, to eliminate the costly impact of the latter project on the local economy. The Moselem project on Maiden Creek was shifted, because of site geology, to a new dam site a short distance upstream and renamed Maiden Creek project. Thus the plan used in planning studies described in subsequent paragraphs included the following projects:

Hawk Mountain	Trexler	Pequest
Prompton (revision)	Maiden Creek	Hackettstown
Tocks Island	Blue Marsh	New Hampton
Bear Creek (revision)	Newark	Tohickon
Beltzville	Christiana	Newtown
Aquashicola	Paulina	French Creek
		Evansburg

150. DIMENSIONS OF MAJOR CONTROL IMPOUNDMENTS. The next phase of analysis in forming the proposed plan of development was the determination of that scale of development for each impoundment site in a system which would produce the greatest net benefits in realizing the balanced program objectives of river basin development. This was achieved in a two phase analysis. First, each of the selected sites was individually analyzed to identify the area of its optimum scale of development in terms of net benefit maximization with consideration given to all water resources products that could be produced by a project at that site. In the second phase, modifications were made at each site's optimum level of development so that the scale of development of each site as an integral part of the balanced program for water resource development would produce only the resource products for which foreseeable markets existed and where the system net benefits would be at a maximum. It is in this latter analysis that the fundamental goal for comprehensive river basin planning is achieved in that the production of required water resource goods and services is accomplished in a manner that cannot be equalled, with regard to balanced production and investments, by any other allocation of productive resources. Indicated below are the methods employed and results obtained in the pursuit of the planning goals of the two phase analysis indicated above.

151. General Procedures - Individual Site Maximization. As indicated above the goal for individual site maximization was to identify for each site that scale of development where the difference between total project costs and total project benefits was at the maximum. As noted in paragraph 78, storage capacity at the major impoundment sites has been divided, in most cases, into short-term storage, capacity required over periods of very short duration to store excess flood flows, and long-term storage, capacity required over extended periods to maintain adequate flow regulation. The product derived from short-term storage is the reduction of flood damages while products derived from long-term impoundments are water supply, recreation, fishing and hunting, low-flow regulation and the generation of hydroelectric power. Exceptions to this general allocation procedure were the Hawk Mountain, Newark and Christiana projects where the entire capacity was assigned to long-term storage and general maximization procedures were not applied. In segregating total storage capacities at major sites between long- and short-term storage and associating the production of specific water resource products to such allocations, it was recognized that in actual operation of a reservoir for its several purposes there would be periods where long-term storage capacity allocated to serve water supply and other needs would be available and would provide effective storage capacity for the impoundment of peak discharges in addition to the short-term storage allocated for that purpose.

Conversely, during extended periods of less than normal runoff when it is desirable to maintain high levels of impounded water in those portions of storage allocated to long-term use there might well be available short-term capacity to assist this operation. To evaluate the nature of such effects in terms of the benefits accruing to flood control from long-term storage and benefits accruing to water supply and recreation from short-term storage would require involved statistical operation studies for each scale of development at each site. Such an appraisal was not considered practical or warranted in this analysis.

152. The first step in this phase of the analysis was the selection of levels of physical development for a given site in terms of the combined allocation of total storage between long- and short-term. The storage allocations used in the selection of the basic plan discussed above were generally used at the point of departure to determine the several levels of development to be evaluated in the present analysis. The levels of development were determined by separate analysis of combinations of each of 5 or 6 levels of long-term storage with as many levels of short-term storage allocations. While for most sites several combinations of long- and short-term allocations would show equal total storage each such combination nonetheless represented a different scale of development since in no two cases are the long or short-term storage allocations similar. Average annual storage costs were assigned to each combination or scale of development based on the combined total of long- and short-term storage allocations. To these storage costs were added the specific costs for recreation and power facilities were applicable. These costs added to the storage costs represent the total average annual charges for each scale of development for each impoundment site.

153. After determination of the annual costs for each scale of development, the benefits associated with each level were then estimated. Average annual flood control benefits were estimated from the short-term storage allocations. Water supply benefits were estimated on the basis of the net yield from each site as determined from the long-term storage allocation less the allocation for inactive capacity. The long-term allocation was also used to determine both the recreation facility costs and recreation benefits. For impoundment sites, where power was being considered as a project purpose, estimates of specific power costs and average annual power benefits were also taken into account for the long-term storage benefits. The total average annual project benefits were then computed for each scale of development by adding together the benefits of flood control, water supply, recreation, and, where applicable, power.

154. Net benefits were computed for each level of development by taking differences between total average annual benefits and costs. That scale of development which would produce the greatest excess of benefits over costs was thereby identified for each site. For each scale of development so identified variations were made within that level of development to assure that no other scale or level would improve either the ratio or net benefit estimate.

155. Values Used. An essential prerequisite of this analysis was that the estimates of costs and values assigned to the purposes served at each project be comparable and consistent for all scales of physical development for each site. It was also necessary that the values used be on a consistent basis to compare any scale of development for one site with any level of development at another major impoundment site. The values used herein, while more refined than those used in earlier analyses, were still preliminary and should not be confused with those monetary evaluations presented in appendix U 28/ and in appendix V which were subject to later refinement. While such values as used herein are considered preliminary they were of both adequate precision and accuracy to permit the relative comparisons undertaken in this phase of the forming of the plan. All costs and benefit values used in this analysis were modified to reflect the January 1959 price level.

156. Average Annual Storage Costs. Average annual storage costs for each scale of development for each major impoundment site were determined through the construction of generalized cost vs. total storage relationships. Estimates of total construction costs of the reconnaissance type were available for several scales of physical development for each major site. For several sites, survey type first cost estimates were also available as quality checks on the reconnaissance type estimates. At those sites where the reconnaissance cost estimates appeared to be inconsistent with either the survey cost estimates for that site or not comparable to similar cost estimates at the other sites modifications were made in the reconnaissance type estimates so that all cost values would be consistent. The estimates included costs for concrete dam, earth embankments, spillway, outlet works, general facilities, access roads, relations, clearing, real estate, contingencies, engineering and construction supervision. For the purpose of this analysis all costs were considered on a uniform

28/ Appendix U, "Project Design and Cost Estimates", prepared by U. S. Army Engineer District, Philadelphia, Department of the Army.

basis equivalent to Federal costs. These total first cost estimates were used to establish the generalized cost/storage relationships for each site for varying levels of total storage allocations. Average annual first costs were obtained by amortizing the total first costs over a fifty-year period at $2\frac{1}{2}$ percent including the interest cost for a four-year initial construction period. Annual charges for operation and maintenance for each major impoundment site were estimated on the basis of the current average annual operation and maintenance cost at existing Corps of Engineer projects most similar in design and costs to the major reservoir sites evaluated in the present analysis. These charges were added in equal amounts to the average annual first costs, irrespective of the scale of development to arrive at the total average annual storage costs for each scale of development at each site studied. Despite the fact that several different levels of physical development in terms of varying long- and short-term storage allocations at a site would result in similar total storage allocations, average annual storage costs for these similar levels of total storage allocation were assigned equally to each such level. It was assumed for this analysis that any cost modifications in design of the site geared specifically to the allocated level of long- and short-term storage would be slight in relation to the overall storage costs.

157. Average Annual Recreation Costs and Benefits. Average annual recreation costs and benefits for each level of long-term storage allocation for each site were determined in the following manner. The National Park Service prepared, for each impoundment site, estimates of annual attendance for two stages of recreation development for a single given long-term storage allocation. The first of these stages of development, designated stage I, was considered as the minimum basic recreation facility level while stage II was defined as an ultimate level for recreation development. National Park Service also provided facility cost data, based on their design criteria, for the two stages of recreation development associated with the given pool elevation at each specific site. The Corps of Engineers then determined real estate costs for land requirements indicated by National Park Service, for each stage of recreation development at the given pool elevation. These first costs for recreation facilities and real estate were combined and amortized over a 50-year period in accordance with standard procedures to arrive at the estimated average annual recreation-only costs for each stage of development. To these were added the estimated average annual charges for recreation operation and maintenance and replacement. In some instances the stage I levels of recreation development were modified to better reflect the minimum basic facility level for recreation development.

158. Annual attendance estimates for other levels of long-term storage allocations at each site were derived from a generalized relationship between surface acres and annual recreation attendance for 59 Corps of Engineer reservoirs throughout the country for which attendance data was available. This relationship was assumed to indicate the effect of reservoir pool size on recreation potentials as reflected by attendance. The difference between the estimated attendance for a given pool at each site as established by the National Park Service and the attendance indicated by the generalized relationship for a pool of equivalent size provided the factor for deriving, for each pool size, the estimated attendance based on the pool size-attendance trend of the generalized relationship. This procedure was followed to obtain estimates of attendance for the several long-term storage allocations under study at the various sites. The estimated current recreation use in visitor-days for the areas above each site subject to inundation, was deducted from the estimated recreation attendance for various storage allocations to obtain estimates for net attendance for each site under consideration.

159. Average annual recreation-only facility and land costs and the estimated annual attendance for that stage of development at the one-pool elevation as determined by the National Park Service were used to obtain average annual cost per visitor-day applicable at that stage of development and storage allocation. Average annual benefits per visitor-day for each site was taken as the average cost per visitor-day of providing comparable recreation facilities at existing state parks in the area. By use of these estimates of annual cost and benefits per visitor-day there were established for each site annual recreation cost and benefit relationships for two stages of development against varying long-term storage pool allocations through use of the expected attendance for each of the two stages of development as determined from the generalized attendance relationship. For the purpose of this analysis the stage I recreation cost and benefit relationship for long-term storage was averaged with the stage II relationship to reflect an average level of development for each site. The two stage recreation development assumed in this phase of the planning studies was discarded later in favor of recreation developments directly and indirectly related to the overall development of water resources at specific projects.

160. Average Annual Flood Control Benefits. The relationship between short-term storage allocations and average annual flood control benefits for each site studied was established in the following manner. With standard procedures to evaluate flood control benefits for an individual project, previously computed

natural discharge-frequency curves for effected flood damage reaches below a proposed impoundment site were modified by the effects of short-term storage allocations at sites under study routed to those downstream damage reaches. The reservoir effects were determined at key downstream reference gages for the flood flows of August 1955, December 1952 and for the Basin Project Flood. The three modified flood flows, thus determined, were the bases for constructing the modified discharge-frequency curves at the downstream damage reaches. These curves were then used to develop the modified damage-frequency relations and to compute the average annual benefits attributable to the short-term storage allocation for each major site.

161. Modified discharge-frequency and modified damage-frequency relations were determined at downstream reaches in the manner described in the paragraph above for several short-term storage allocations at each site. Thus for each site a relationship of short-term storage vs. average annual flood control benefits was developed throughout the range of contemplated short-term storage allocations. The estimates of flood control values for each level of short-term storage allocation determined in this manner reflected 1958 levels of physical development in the flood plains. Such values were then escalated to estimate the probable level of physical development which would reflect the average level of annual flood control benefits over the life of the project. This was accomplished through the application of trend of flood plain development indexes developed in appendix D. For the purposes of this analysis total flood control benefits were prorated to individual sites on the basis of each site's individual effects.

162. Average Annual Benefits from Supplies of Water. Average annual water supply benefits for each site were associated with several levels of long-term storage allocation and were obtained in the following manner. For the purpose of this analysis, the physical water supply product was evaluated in terms of the net yield in c.f.s. obtainable from the several levels of long-term storage allocation. Since each major impoundment site possessed unique storage-yield relationships, equivalent long-term storage allocations of several sites would not necessarily produce equivalent net yield discharge. The net yield relates directly to the production of supplies of water that, in turn, represent monetary benefits. Monetary benefit measures, applied to each site's levels of net yield, defined a relationship of long-term storage vs. water supply benefit. The measure of the water supply benefit to be assigned to the several levels of net yield (as determined from the long-term storage allocation) was obtained by computing the cost of providing an equivalent net yield from the most likely alternative source that would be utilized in the absence of the project under analysis.

163. The application of the above mentioned general procedure in the specific impoundment sites required several modifications. For instance, in the Lehigh River Basin, it was not possible to establish the timing of the major projects until the maximization studies could be completed. Accordingly, there existed no basis for indicating those sites which could justifiably be considered as the next most likely alternative source. In lieu of an appraisal based on the most likely alternative, each site in the Lehigh Basin was treated as if it were the first site to be development and the average annual water supply benefits for any one major impoundment site was taken as the average cost of obtaining similar yields from the remaining sites. A similar procedure was used for the Maiden Creek project in the Schuylkill River Basin.

164. With respect to the Tocks Island impoundment site the application of the alternative cost as a measure of water supply benefits was employed only up to that scale of development at Tocks Island for which real alternatives existed. Beyond this scale there did not exist a real alternative to Tocks Island water supply. In this case it was reasonable to assume that the additional water supply benefits attributable to the increases in the scale of development would at least be equal to the cost of obtaining it at that site. Since the relationship of long-term storage vs. water supply benefits defined by the cost of alternates and by the at-site costs showed no distortion or abrupt break, it was considered a sound basis for evaluating water supply benefits at this site. Water supply benefits for the Blue Marsh project in the Schuylkill River Basin were evaluated in a similar manner.

165. Average annual water supply benefits for each major impoundment site at several scales of long-term storage allocations were then modified to take into account any lag in the accrual of water supply benefits with respect to the time pattern of water demands. For this purpose it was assumed that each site would be developed within the next five to ten years without regard to any chronological sequence of construction. On the Lehigh River, since no one site to be developed over the next decade would fully meet the projected water demands, it was reasonable to assume that each site would attain its full average annual water supply benefit in the initial development period. It was therefore not necessary to modify the water supply benefits in this case. With respect to the Tocks Island site and the impoundment sites on the Schuylkill River it was necessary to modify their average annual water supply benefits by appropriate discounting procedures, since the projected pattern of water supply demands indicated that not all of the yield to be obtained from these sites would be required during the early life of each project. In this way the modified benefit estimates at these sites better reflected the average level of water supply benefit accrual with respect to the projected requirements for water supply.

166. Average Annual Power Costs and Power Benefits. Tocks Island was the only major impoundment site in the maximization studies where the generation of hydroelectric energy was considered. Tocks Island power potential was first analyzed on the basis of power generation at several levels of power potential from 20 percent load factor to 100 percent load factor operated at 95 percent dependability. Power values were furnished by the Federal Power Commission. Details of these studies are contained in appendix T. For the purpose of the individual site maximization studies, the selection of the type of generating plant, in terms of a load factor, to be included in the overall Tocks Island maximization study was based on that type of load generation which produced the maximum excess benefits. Studies indicated that the greatest net excess power benefits accrued at a plant with a (100 percent) base load factor. This finding basically reflected the costly reregulation required by plants primarily designed for peak power installations with a lesser load factor.

167. Estimates of specific power costs and power benefits based on the (100 percent) base load plant were then developed for several levels of long-term storage allocation at the Tocks Island site. From these estimates a generalized relationship of power cost-power benefit vs. storage was established for the range of long-term storage allocations being considered for Tocks Island. Since the projected energy requirements in the basin area are far in excess of the energy that could be produced from Tocks Island it was reasonable to assume that all potential power benefits at Tocks Island would accrue at the time Tocks Island would be developed.

168. Results of Individual Site Maximization Studies. Individual site maximization procedures were systematically applied to each major impoundment site considered in this phase of the analysis employing the appropriate benefit and cost values as discussed above. The results of these studies are shown graphically in plate Q-8. Each figure on this plate shows for each of the major impoundment sites the range of net benefit accrual at each site with respect to a series of short-term/long-term allocations. The point at which the net benefit accrual is maximized is labelled Maximum in each figure. At these points the differential between total project costs and total project benefits is at a maximum. The pertinent data for each site at its maximized scale of physical development are shown below in table Q-17.

TABLE Q-17

SCALES OF DEVELOPMENT
INDICATED BY INDIVIDUAL SITE MAXIMIZATION

Project	Inactive (ac.ft.)	Long-Term (ac.ft.)	Short-Term (ac.ft.)	Total Capacity (ac.ft.)
Beltzville	1,200	60,000	25,000	86,200
Aquashicola	1,000	31,000	20,000	52,000
Trexler	800	24,200	10,000	35,000
Blue Marsh	1,500	28,500	19,000	49,000
Maiden Creek	2,000	78,000	30,000	110,000
Tocks Island	80,000	440,000	250,000	770,000
Bear Creek	2,000	70,000	108,000	180,000

The particular allocations of storage indicated in the above table represent those levels of development indicated by maximization of net monetary returns. It is recognized, however, that there are some areas of the benefit picture which are not directly susceptible to monetary appraisal. Such intangible benefits, while not entering directly into the maximization analysis, had to be taken into consideration in order to assure a truly balanced plan for optimum satisfaction of all water resources needs. Modification of maximized scales of development to allow for such intangibles are discussed in the following paragraphs.

169. Of particular significance in the evaluation of the maximization studies is the apparent flatness of the net benefit accrual curves around the point of net benefit maximization. This can be seen in figures 1 and 3 of plate Q-8 for the Beltzville project and Aquashicola project, respectively. For instance, on the Beltzville project (figure 1), a reduction by as much as 32% in the long-term storage allocation at the 61,000 acre-foot allocation where net benefits are maximized would only result in the loss of $10,000 of annual net benefits, only about a 5% reduction from the maximum excess estimate of $197,000. Similarly a 40% reduction in the short-term storage allocation for the Beltzville site, holding long-term storage at the maximum level, would result in a loss of annual net benefits of $7,000, a 3½ percent reduction from the maximized point. For the Aquashicola project (figure 3), a reduction of long-term storage by 20% from that project's net benefit maximization point leaves the net benefit estimate virtually unchanged. A reduction of the same percentage in the short-term storage allocation would only reduce net benefits at Aquashicola by 2½%.

170. Conversely, increases in storage allocations do not always appear to severely alter the level of net benefit accrual. For instance, for the Trexler project (figure 2), an increase of short-term storage from 10,000 acre-feet to 14,000 acre-feet, a 40% increase in the short-term storage allocation, only reduces annual net benefits by $6,000, about 5% of the $118,000 net benefit level at the maximum point. A 20% increase in Trexler's long-term storage allocation results in a benefit reduction of $2,000, almost no loss of net benefits. On the other hand, changes of storage allocations for the Blue Marsh project from its maximized level results in major modifications in the net benefit estimates. For instance, an increase of short-term storage from 19,000 acre-feet to 25,000 acre-feet, an increase in short-term storage of 32%, results in a loss of $27,000 of annual net benefits, 14% of the total excess benefits at Blue Marsh's level of optimum development. For the Tocks Island project the unusual capacity-cost relationship reflecting the cost of protective work in the vicinity of Matamoras and Port Jervis resulted in a relatively confined area, as shown by figure 7, within which net benefits can be maximized.

171. The importance of the apparent flatness and other peculiarities of net benefit accrual curves around each site's point of net benefit maximization is that it will not be possible to make modifications in the scale of development at any one site from the maximized level without seriously altering the maximized net benefit estimate. This zone of maximization permitted the necessary scale of development changes at each site so that it was possible to determine a system of projects that would achieve a balanced program of development without seriously violating maximization principles.

172. MODIFICATIONS. While for the purposes of this phase of the forming of the plan of development a single level of physical development for each major impoundment site was identified as the level with the greatest net benefit accrual, the results of these studies, as noted above, indicates that for each project there existed a range or zone of other levels of development where the difference between net benefits at the maximum level and at some lesser level was very small in terms of net benefit reduction. On a *prima facie* basis it would appear desirable that each project selected for inclusion as an integral unit of a system of projects be developed exactly to the scale of development producing maximum excess benefits. It was fully recognized, however, that before it would be possible to choose the final dimensions of any one site to be included within a system, it would be necessary to reevaluate each site with respect to its contribution in the attainment of a balanced program of development which could not be fully evaluated within the constraints of the individual site maximization studies. Two major areas

considered in the reevaluation of the dimensions of the impoundment sites were (1) the degree of flood control protection to be afforded from each site in relation to desirable levels of production indicated by other criteria and (2) the adequacy of the several projects considered as a system in meeting the 50-year time pattern of net surface water requirements for water supply. Another equally important consideration was the cultural or geographic limitations of individual site development that could not be fully evaluated in monetary terms in the maximization studies. The following paragraphs will indicate the nature of such modifications and the reasons behind each. Following this, the results of these modifications are summarized with respect to the resultant changes in overall net benefit accruals.

173. Short-Term Storage Allocations. Studies were first undertaken to determine the effectiveness of each project, sized in accordance with the results of the individual maximization, to reduce or control flood flows in terms of the degree of reduction of the Standard Project Flood for each site. Based upon the short-term storage allocations from maximization studies associated with the reduction of flood damages, the following determinations were made:

Project	Short-Term Storage (ac.ft.)	Degree of Protection* (percent)
Tocks Island	250,000	- 50
Beltzville	25,000	62
Aquashicola	20,000	77
Trexler	10,000	51
Maiden Creek	30,000	46
Blue Marsh	19,000	32
Bear Creek	108,000	- 70

* The extent to which the volume of the Standard Project Flood at the site can be impounded. Complete impoundment = 100%

While it was recognized that the short-term storage allocations indicated above contributed to the production of the maximum net excess benefits for each site, it was still necessary to give further attention to the possibility of a higher degree protection to be afforded to downstream reaches in excess of the protection achieved solely through the short-term allocations based on the results of the maximization studies. The attainment of a balanced program for flood damage reduction could not be evaluated on economic efficiency criteria alone. The presence of major urban development in downstream reaches from each of the major impoundment sites required, in addition to providing the greatest dollar damage

reduction for each dollar of investment, a sufficiently high degree of protection so as not to create any false sense of security that would possibly aggravate the flood problem.

174. In light of these considerations short-term storage allocations at the Beltzville, Trexler, Maiden Creek, and Blue Marsh projects were modified to provide additional short-term capacity thereby increasing the degree of protection. Wherever possible, these modifications were made within each project's zone of maximization so that the net result would be to increase the degree of protection while at the same time minimize the loss of net benefits. The results of these modifications are shown below:

Project	Short-Term Storage (ac.ft.)	Degree of Protection (percent)
Tocks Island	275,000	54
Beltzville	27,000	71
Aquashicola	20,000	77
Trexler	14,000	66
Maiden Creek	38,000	55
Blue Marsh	33,000	52
Bear Creek	108,000	- 70

175. Long-Term Storage Allocations. Modifications were also undertaken on the long-term storage allocations to adjust for geographic and cultural limitations on site development and to insure that the yield to be produced from each site considered as integral parts of a system would be no more needed to satisfy net surface water requirements by the year 2010. The former type modifications were necessitated by the several modifications made in short-term allocations as indicated above in paragraph 174.

176. At the Blue Marsh site, it was found necessary to reduce long-term storage from 30,000 acre-feet at the maximized point to 16,000 acre-feet, a net reduction of 14,000 acre-feet. The maximization studies at this site reflect the prohibitively high cost of project developments in excess of total storage capacity of 50,000 acre-feet due to the cost of protecting or relocating the town of Bernville, Pennsylvania, for the higher development capacities. Inasmuch as it was desirable to increase Blue Marsh's short-term allocation by 14,000 acre-feet to provide a reasonable degree of flood control protection, it was necessary to reduce the long-term allocation by a similar amount. In this way it was possible to achieve a reasonable degree of flood control protection with minimal loss of net benefit accrual. Any other reallocation of long-term capacity with respect to the required short-term modification

would have resulted in further losses of net benefits. While the evaluation used for long-term and short-term storage showed a substantial reduction in the net benefits for the modified storage allocations, these net benefit reductions would be minimized or possibly eliminated if methods were available for monetary appraisal of the assurance value of reasonable degrees of flood control. A loss of net yield for water supply resulted also from these modifications, but the modified long-term storage would provide sufficient yield at this site to satisfy that area's water demands with the Maiden Creek project also considered. At the Maiden Creek site, a slight reduction of long-term storage was undertaken to minimize the loss of net benefits as a consequence of modification of Maiden Creek's short-term capacity. Long-term storage was reduced from 80,000 acre-feet to 76,000 acre-feet, with a resultant loss of yield of approximately only 2 c.f.s. This, however, did minimize the reduction of net benefits.

177. As indicated previously there existed a limitation on development of the site at Tocks Island beyond elevation 428 where the cost of protecting the Port Jervis area prohibited economically justified developments in terms of net benefit accrual. Since it was necessary to increase the short-term allocation at Tocks Island by 25,000 acre-feet to afford a higher degree of flood control protection, it was also necessary to adjust the long-term allocation so as to keep the pool elevation within the critical level. The long-term allocation therefore suffered a reduction of approximately 30,000 acre-feet. The loss of both net benefits and net yield as a consequence of these modifications were minor by comparison with this site's overall ability to contribute to the balanced program of resource development for this basin.

178. In the case of the projects in the Lehigh River basin, (Aquashicola, Bear Creek, Beltzville and Trexler), modifications of long-term storage were indicated since the cumulative sum of net yields from each of these projects individually maximized would be in excess of the augmentation requirement from these sites to satisfy both the water supply demands in the Lehigh and Trenton-Philadelphia areas by 2010. From the results of the maximization studies these four sites could produce a net yield of 433 c.f.s. However, a combined net yield of only 408 c.f.s. was considered adequate to satisfy the augmentation requirements. Within the environments of this study it would be necessary to reduce the combined net yield by 25 c.f.s. so that only the required augmentation would be produced. However, with expected increases in water needs after year 2010 such reduction seemed unreasonable at this stage of planning for the development of the basin's water resources and, accordingly, was not made a feature of this study.

179. Since the yield at any one site could be directly substituted for yield from any of the remaining sites, it was only necessary to study the relative efficiency of the site's ability to produce net yields and reduce the net yield excess from those sites with the lowest relative efficiency. The results of the maximization studies did reveal, however, that Bear Creek possessed a unique economic advantage in its relative efficiency to produce a unit of yield. It was evident that no advantage would be obtained by reducing Bear Creek's yield from its maximized level. On the other hand, while it could be argued to increase the yeild of Bear Creek at the expense of larger reductions at the other sites to achieve the desired augmentation of 408 c.f.s. in an efficient fashion, the results of such modifications would seriously impair the ability of the Trexler, Beltzville and Aquashicola sites to produce flood damage reduction and recreation on an economically justified basis. The relative loss in the production of flood control and recreation benefits at these sites would be greater than the efficiency gained in producing more water supply yield at Bear Creek. Based upon these considerations no modifications were made on Bear Creek's long-term storage allocation of 72,000 acre-feet, capable of producing 208 c.f.s. of net yield. With Bear Creek fixed at a level of 208 c.f.s. it was then necessary to reduce the net yield from the remaining sites by 25 c.f.s. so that the combined net yield of the three sites would equal 200 c.f.s.

180. To select the final dimensions of the Trexler, Aquashicola, and Beltzville sites to produce a combined net yield of 200 c.f.s. required a special maximization study of these three sites in combination. Short-term storage allocations for each site were set at their modified levels as discussed in paragraph 174. For each site a series of net yield levels were arrived at by varying the long-term storage allocation. The net benefit accrual for each level of yield for each site was then computed in accordance with maximization procedures discussed earlier. It was then possible to develop a series of combinations of the three projects with each combination always producing 200 c.f.s. For each such combination a total net benefit estimate was also computed.

181. Employing increments of 5 c.f.s. net benefit, estimates were computed for over 200 different combinations of the three reservoirs scaled to varying degrees of long-term storage allocation each combination producing 200 c.f.s. It should be noted, however, that while the degree of flood protection remained constant throughout, as well as the cumulative net yield, variations did occur in the level of net recreation benefits which, as discussed earlier, were directly related to the level of long-term storage for each major site. That combination which produced the maximum excess benefits was selected as the final basis for modification of long-term storage at these sites so that the required

flow of 200 cfs from these sites would be secured. This combination called for a net yield of 55 c.f.s. from the Trexler site, requiring a long-term storage allocation of 25,000 acre-feet exactly equal to the allocation arrived at in the original maximization study. From the Beltzville site, a yield of 82 c.f.s. would be required associated with 41,200 acre-feet of long-term storage, 20,000 acre-feet less than the allocation in the maximization studies. Lastly, a requirement of 63 c.f.s. was determined for the Aquashicola site, associated with 25,000 acre-feet of long-term storage, some 7,000 acre-feet less than the allocation of 32,000 acre-feet determined in the course of the maximization studies.

182. Results of Modification. Throughout the process of storage modifications careful note was taken of the changes occurring in the level of net benefit accrual as the level of development for each site varied. The goal of these modifications was not only to provide bases for fixing the dimensions of the individual projects within the realities of the planning environments but also to establish storage allocations designed to optimize, within practical limits, the net benefits. Since for most sites there existed a rather broad zone of maximization, modifications in storage allocations were possible without serious effect on the net benefits. The results of the above mentioned modifications in long- and short-term storage allocations in terms of net benefit reduction are given below and are shown on plate Q-8.

NET BENEFITS

Project	Individually Maximized	Modified
Tocks Island	$1,550,000	$1,400,000
Betlzville	197,000	185,500
Aquashicola	160,500	159,000
Trexler	118,000	111,000
Maiden Creek	44,000	41,000
Blue Marsh	191,000	114,000
Bear Creek	813,000	No Change

The adopted storage allocations showed an overall reduction of eight percent in net benefits from the maximum established for the seven projects by the maximization studies.

183. <u>SEQUENCING AND TIMING OF PROJECTS</u>. Having formed the basic plan of development, the next step was to establish a procedure to determine the orderly sequence for individual project development and to indicate at what time in the future each project or element of the plan would be required for full utilization. Several avenues of approach were available for this purpose. One approach considered was to select that sequence for major impoundment sites which would maximize the accrual of net benefits for the entire eleven projects in this group over the ensuing fifty-year planning period. For this purpose approximately ten different sequences were formulated and evaluated with respect to net benefit accruals. While this approach did result in a sequence that maximized the entire accrual of net benefits, the fact that the sequence with the lowest net benefit accrual only differed from the maximized sequence by 2½% prompted closer investigation of the reasons behind even this relatively small variation. It was determined that variation could almost solely be traced to the particular shape of the average demand curve for supplies of water. Depending upon the sequence of any one project with respect to time, there resulted a slight shift in the overall net benefit accrual as the period of full growth for supplies of water varied within a range of from two to four years. Recognizing the range within which the requirements for supplies of water would undoubtedly vary in the future, it was concluded that no one sequence could clearly result in a major economic advantage with respect to the accrual of system net benefits.

184. The assignment of a time sequence to the eleven major impoundment projects was finally achieved by the approach of seeking a balanced program of resources development to adequately cope with the planning environment of "time" and "area" discussed earlier in this appendix. There exists an immediate market for all flood control measures, development of additional recreational opportunities and the generation of hydroelectric power. While there are also several areas with immediate requirements for flow augmentation for supplies of water, for most part the major augmentation requirements will not be needed for fifteen or twenty years hence. The problem of sequence resolved itself into the question of which sequence would best serve the region in producing the required goods and services in a timely fashion so as to minimize the foregoing of current production of required products while at the same time minimizing current production of those for which substantial markets would not exist for some years in the future.

185. For instance, in the Lehigh problem area where there are immediate markets for all products it would not appear reasonable to schedule the raising of Bear Creek for the immediate future. While Bear Creek would adequately satisfy the market for supplies of water in the Lehigh for some twenty years, major flood control and recreation benefits would be foregone since early construction

of Bear Creek would delay the time that Beltzville, Aquashicola, and Trexler would be needed for flow augmentation. To schedule all these projects for the near future would clearly result in a misallocation of resources.

186. While sizeable flood control, recreation and power benefits could be immediately realized from early development of the Tocks Island project, early development of several other major impoundment sites needed in the Lehigh and Schuylkill River basins would contribute to satisfaction of demands for supplies of water in essentially the same area that would be served from Tocks Island. This duplication of service mitigates against the early development of Tocks Island because a sizeable allocation of Tocks Island storage for long-term use would not be required for some years in the future. On the other hand, the magnitude of the value of the other products to be secured from Tocks Island requires that this project not be delayed too long and to supersede the development of other major control projects.

187. Based upon these kinds of consideration the following project sequence for the major impoundment sites was established:

Project	Required by Year
Beltzville	1965
Blue Marsh	1969
Trexler	1972
Prompton	1974
Newark	1975 (a)
Tocks Island	1975
Christiana	1980 (a)
Aquashicola	1981
Maiden Creek	1982
Bear Creek	1989
Hawk Mountain	2001
39 Upstream Reservoirs	(b)

(a) Subject to development of Upper Brandywine by the Commonwealth of Pennsylvania.
(b) At earliest date all requirements are met to permit construction under existing programs.

It should be borne in mind that the dates specified in the above sequence are flexible depending upon post planning evaluations of future requirements for supplies of water and other resource derivatives. Indeed, the sequence itself has some flexibility in that certain projects may be shifted without seriously violating

the attainment of a balanced program of development. For instance, the Beltzville project could be exchanged with either the Trexler or Aquashicola project and so on. Similarly, the Blue Marsh and Maiden Creek projects may be exchanged with each other in the above sequence. The same would be true of the Newark and Christiana projects.

188. PLAN OF DEVELOPMENT. From the studies reported in the above paragraphs it appears that the broad basinwide demands for the products and services of water resources development may be met most efficiently and economically by a group of eleven major impoundments. The dimensions of these impoundments, sized to maximize net benefits with assured balance of products and dependableness of services, are listed in table Q-17. During the studies to define this plan it became apparent that major impoundments were required to cope with the scale of needs projected into the future for the basin and its water service area. As pointed out above in section V, a plan of development defined solely in terms of major impoundments would not necessarily constitute the optimum plan for all levels of land use and development. Studies of farming practices and land use reported in appendix K show the need for watershed management, including land treatment and structural works of improvement, as an essential element in a program of use and control of the water resources of the basin. Studies of the needs at the intermediate upstream levels of land use and development as reported in appendix R show that 39 upstream reservoirs are economically feasible as means of satisfying flood control needs in local areas. In paragraph 148 above, the need is indicated for development at an early date of eight sites for recreation initially and for water supply and other purposes ultimately. In appendix I the need is established for the acquisition and preservation for recreation purpose of seven existing water areas with significant recreation and scenic potentials. The physical elements of the plan of development include, in addition to watershed management features, 65 impoundments of various dimensions and for various purposes as shown in table 18. In addition to the physical elements, the comprehensive plan must include:

a. The extension of programs to collect basic data on water use and water quality,

b. The extension and expansion of waste removal programs to preserve and improve the quality of the water resources of the basin,

c. Programs to control the use of land in the flood plains,

TABLE Q-18

MAJOR WATER IMPOUNDING PROJECTS

(Listed according to geographical location, North to South, only)

Project	Drainage Area Gross (sq.mi.)	Drainage Area Net (sq.mi.)	Long Term Inactive Capacity (ac.ft.)	Long Term Inactive Elevation Top of Pool (ft. m.s.l.)	Long Term Active Capacity (ac.ft.)	Long Term Active Elevation Top of Pool (ft. m.s.l.)	Short Term Capacity (ac.ft.)	Short Term Elevation Top of Pool (ft. m.s.l.)	Total Capacity (ac.ft.)	Total Elevation Top of Pool (ft. m.s.l.)
Hawk Mountain	812	440 (a)	60,000	1,008.0	233,000	1,082.0	-	-	293,000	1,082.0
Prompton	60	60	3,400	1,125.0	28,000	1,180.0	20,300	1,205.0	51,700	1,205.0
Tocks Island	3,827	2,412 (b)	80,000	356.0	410,000	410.0	275,000	428.0	765,000	428.0
Bear Creek	288	288	2,000	1,300.0	70,000	1,425.0	108,000	1,481.0	180,000	1,481.0
Beltzville	97	75 (c)	1,200	525.0	40,000	615.0	27,000	641.0	68,200	641.0
Aquashicola	66	66	1,000	435.0	24,000	483.0	20,000	503.0	45,000	503.0
Trexler	51	51	800	416.0	24,200	479.0	14,000	492.0	39,000	492.0
Maiden Creek	161	161	2,000	323.0	74,000	381.0	38,000	394.0	114,000	394.0
Blue Marsh	174.5	174.5	1,500	249.0	14,500	279.0	33,000	303.0	49,000	303.0
Newark	67	67	1,000	98.0	30,000	156.0	-	-	31,000	156.0
Christiana	41	41	1,000	23.0	36,000	49.0	-	-	37,000	49.0

(a) Below Pepacton Reservoir
(b) Below Cannonsville, Pepacton, Hawk Mtn., Neversink and Prompton Reservoirs
(c) Below Wild Creek Reservoir

DELAWARE RIVER BASIN REPORT

APPENDIX Q | ERRATA SHEET | 3 January 1961

Table Q-19. Add the following projects:

"Green Lane	-	-	-	-	Recreation"
"Haycock Mt.	-	-	-	-	Recreation"
"Shohola Falls	-	-	-	-	Recreation"
"Warner Lakes	-	-	-	-	Recreation"
"Reservoir WA-5A - Brandywine Basin - 175(d)				-	Recreation"
"Raritan Arsenal	-	-	-	-	Recreation"
"W. Cape May Beach	-	-	-	-	Recreation"
"Cox Hall Creek	-	-	-	-	Recreation"
"Delaware Dunes	-	-	-	-	Recreation"
"Churchman's Marsh	-	-	-	-	Recreation"
"Cooch's Bridge	-	-	-	-	Recreation"
"Buena Vista	-	-	-	-	Recreation"
"McDonough House	-	-	-	-	Recreation"
"Cape Henlopen	-	-	-	-	Recreation"
"Woodland Beach	-	-	-	-	Recreation"
"Augustine Beach	-	-	-	-	Recreation"

Note:
Pertinent information to make this addendum compatible with column headings in Table Q-19 to be included in final revision.

See Errata Sheet 3 Jan 61
filed in front of this sheet

TABLE Q-19
ELEMENTS OF PLAN OF DEVELOPMENT
(Listed geographically)

Project	Stream or Subbasin	Total Capacity in Acre-Feet	Project Purposes
WA-16	W.Br. Delaware R. basin	4,730	Flood Control and Recreation.
ON-2	W.Br. Delaware R. basin	870	Flood Control and Recreation.
Hawk Mountain	E.Br. Delaware R.	293,000	Supplies of Water, Recreation and Power.
LM-2	Callicoon Creek basin	3,040	Flood Control and Recreation.
Prompton	Lackawaxen R.	51,700(a)	Supplies of Water added to existing Flood Control and Recreation.
Tocks Island	Delaware R.	765,000	Supplies of Water, Flood Control, Recreation and Power.
BU-1	Brodhead Cr. basin	1,170	Flood Control and Recreation.
PC-5	Brodhead Cr. basin	340	Flood Control and Recreation.
PC-2	Brodhead Cr. basin	580	Flood Control and Recreation.
PC-7	Brodhead Cr. basin	340	Flood Control and Recreation.
BU-5	Brodhead Cr. basin	540	Flood Control and Recreation.
BU-6	Brodhead Cr. basin	600	Flood Control and Recreation.
BU-7	Brodhead Cr. basin	270	Flood Control and Recreation.
PC-1	Brodhead Cr. basin	1,060	Flood Control and Recreation.
PC-11	Brodhead Cr. basin	490	Flood Control and Recreation.
PC-6	Brodhead Cr. basin	230	Flood Control and Recreation.
PC-10	Brodhead Cr. basin	730	Flood Control and Recreation.
Swiftwater (PC-9)	Brodhead Cr. basin	3,350	Flood Control and Recreation.
Parkside (PC-8)	Brodhead Cr. basin	2,270	Flood Control and Recreation.
BU-10	Brodhead Cr. basin	560	Flood Control and Recreation.
PC-14	Pocono Cr. basin	1,240	Flood Control and Recreation.
PC-15	Pocono Cr. basin	560	Flood Control and Recreation.
PC-17	Pocono Cr. basin	270	Flood Control and Recreation.
PC-12	Pocono Cr. basin	380	Flood Control and Recreation.
PC-13	Pocono Cr. basin	320	Flood Control and Recreation.
PC-16	Pocono Cr. basin	270	Flood Control and Recreation.
PC-20	Pocono Cr. basin	380	Flood Control and Recreation.
PC-21	Pocono Cr. basin	470	Flood Control and Recreation.
PC-18	Pocono Cr. basin	780	Flood Control and Recreation.
PC-19	Pocono Cr. basin	540	Flood Control and Recreation.
PC-22	Pocono Cr. basin	380	Flood Control and Recreation.
Paulins	Paulins Kill	(c)	Recreation initially with Supplies of Water and Other Purposes ultimately.
Pequest	Pequest R.	(c)	Recreation initially with Supplies of Water and Other Purposes ultimately.
DC-1	Martins Cr. basin	550	Flood Control and Recreation.
WG-5	Bushkill Cr.	5,540	Flood Control and Recreation.
Bear Creek	Lehigh R.	180,000(b)	Supplier of Water added to existing Flood Control and Recreation.
Jim Thorpe (Hz-6)	Mauch Chunk Cr.	1,530	Flood Control and Recreation.
Beltsville	Pohopoco Cr.	68,200	Supplies of Water, Flood Control and Recreation.
Aquashicola	Aquashicola Cr.	45,000	Supplies of Water, Flood Control and Recreation.
Trexler	Jordan Cr.	39,000	Supplies of Water, Flood Control and Recreation.
WG-1	Monocacy Cr. basin	460	Flood Control and Recreation.
Hackettstown	Musconetcong R.	(c)	Recreation initially with Supplies of Water and Other Purposes ultimately.
New Hampton	Musconetcong R.	(c)	Recreation initially with Supplies of Water and Other Purposes ultimately.
Tohickon	Tohickon Cr.	(c)	Recreation initially with Supplies of Water and Other Purposes ultimately.
GT-10	Neshaminy Cr. basin	2,770	Flood Control and Recreation.
GT-11	Neshaminy Cr. basin	2,520	Flood Control and Recreation.
Newtown	Neshaminy Cr.	(c)	Recreation initially with Supplies of Water and Other Purpose ultimately.
GT-7	Tacony Cr. basin	460	Flood Control and Recreation.
Maiden Creek	Maiden Cr.	114,000	Supplies of Water, Flood Control and Recreation.
Blue Marsh	Tulpehocken Cr.	49,000	Supplies of Water, Flood Control and Recreation.
French Creek	French Cr.	(c)	Recreation initially with Supplies of Water and Other Purposes ultimately.
Evansburg	Skippack Cr.	(c)	Recreation initially with Supplies of Water and Other Purposes ultimately.
WT-1	Stony Cr. basin	500	Flood Control and Recreation.
WT-2	Stony Cr. basin	570	Flood Control and Recreation.
GT-4	Wissahickon Cr. basin	460	Flood Control and Recreation.
GT-13	Wissahickon Cr. basin	250	Flood Control and Recreation.
Baron Hills - Milford Mills	Brandywine R. basin	420(d)	Recreation.
Newark	White Clay Cr.	31,000	Supplies of Water and Recreation.
Becks Pond & Sunset Lake	New Castle Co., Del.		Recreation.
Smalleys Pond	New Castle Co., Del.	60(d)	Recreation.
Christina	Christina R.	37,000	Supplies of Water and Recreation.
Lums Pond	New Castle Co., Del.	200(d)	Recreation.
Killen-Coursey McCauley Pond	Murder Kill R., Del.	200(d)	Recreation.
Red Mill Pond	Broadkill basin, Del.	150(d)	Recreation.
Voshell Pond	Kent Co., Del.	31(d)	Recreation.

(a) Includes 23,700 acre-feet of existing short term storage.
(b) Includes 110,000 acre-feet of existing short term storage
(c) Initial capacity to be consistent with recreation requirements with ultimate capacity to serve recreation, water supply and other purposes.
(d) Surface area in acres of existing water impoundment.

d. A basinwide program to control the use of groundwater and surface water resources,

e. Programs to create general acceptance for the repetitive use of surface waters of the basin,

f. Programs leading to conservation of water use,

g. Programs of research leading toward continued and expanded use of the fishing and wildlife resources,

and h. Programs to manage forestry in recreation and reservoir areas.

VII SUMMARY

189. This appendix has presented a plan for optimum development of the water resources of the Delaware River Basin. The planning environments and evolution of planning procedures were described in detail. The planning goals and alternate measures of achieving them were discussed. The recommended plan consists of 19 major impoundments, 39 small impoundments and a series of recommended related programs. Of the 19 major impoundments, 11 multi-purpose projects were found to be needed prior to 2010 and 8 major impoundments suitable for initial recreation development prior to 2010 were found to be required for additional supplies of water after 2010. Optimum scales of development and approximate times were given for the major multi-purpose impoundments needed prior to 2010. Principles of and procedures for net benefit maximization were described in detail. Construction of 39 small flood control reservoirs and implementation of supplementary related programs are subject to desires and administration of local interests.

GROUPINGS of COUNTIES in the Delaware River Service Area

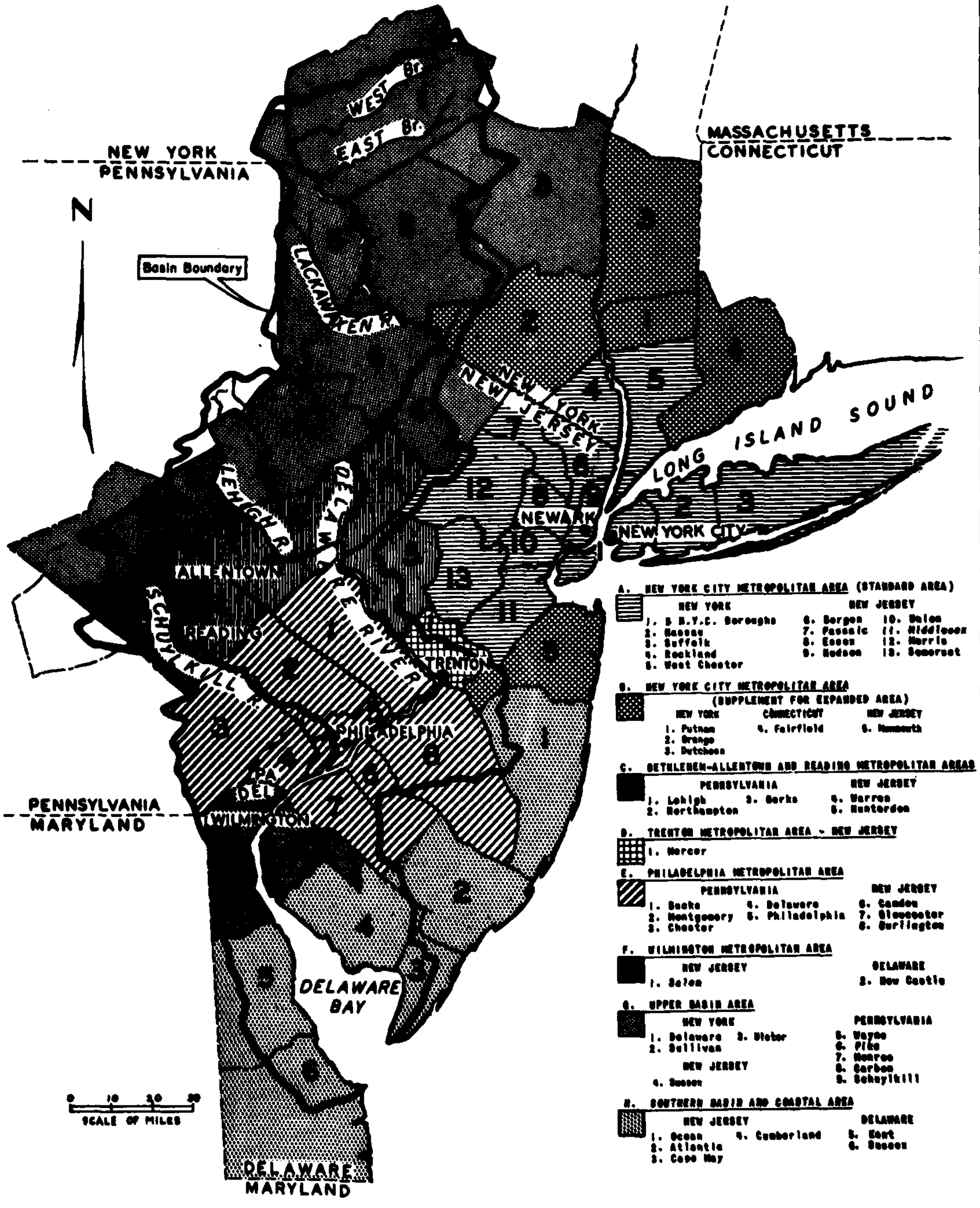
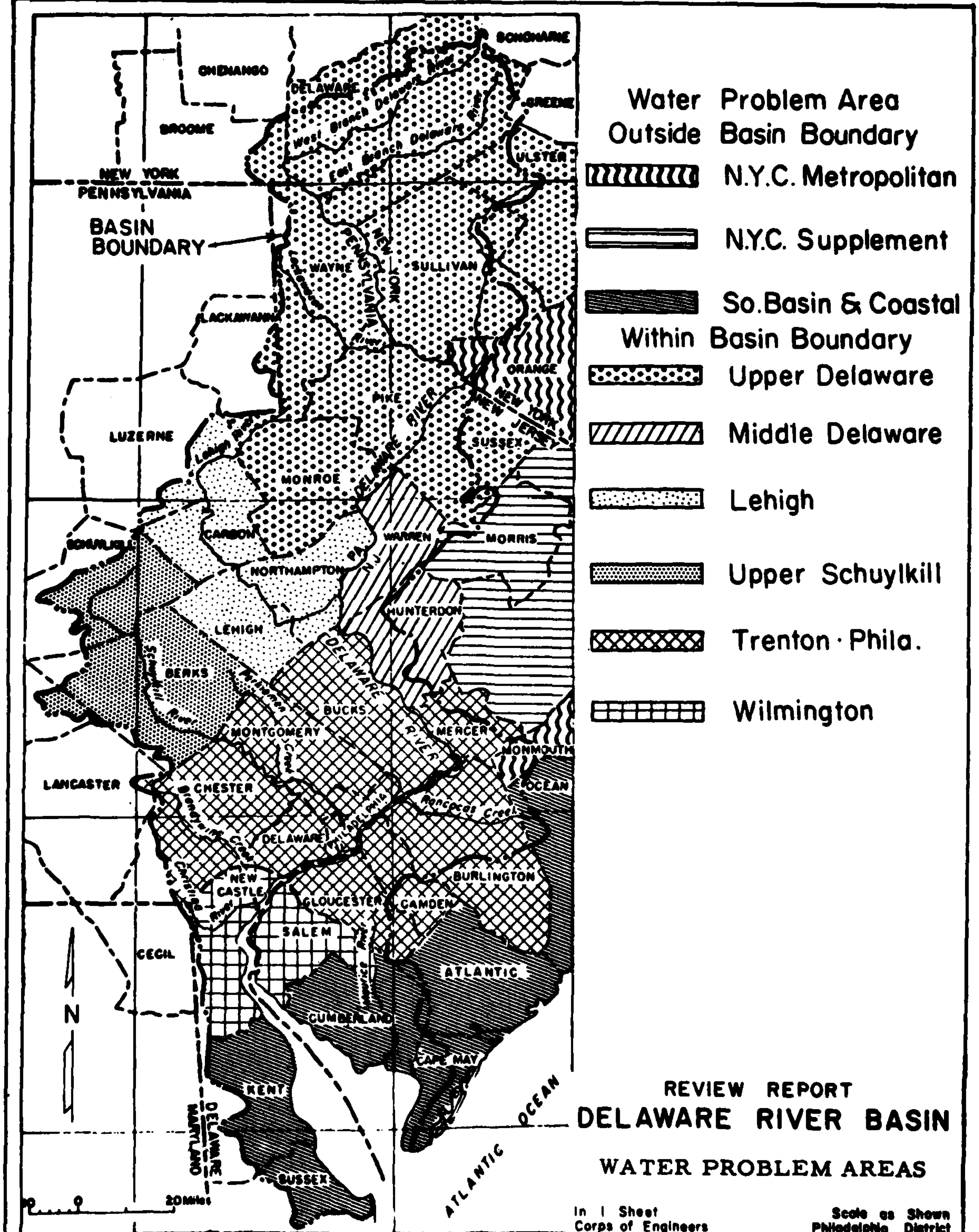


PLATE I

CORPS OF ENGINEERS U.S. ARMY



REVIEW REPORT

DELAWARE RIVER BASIN

WATER PROBLEM AREAS

In 1 Sheet
Corps of Engineers
Philadelphia, Pa.

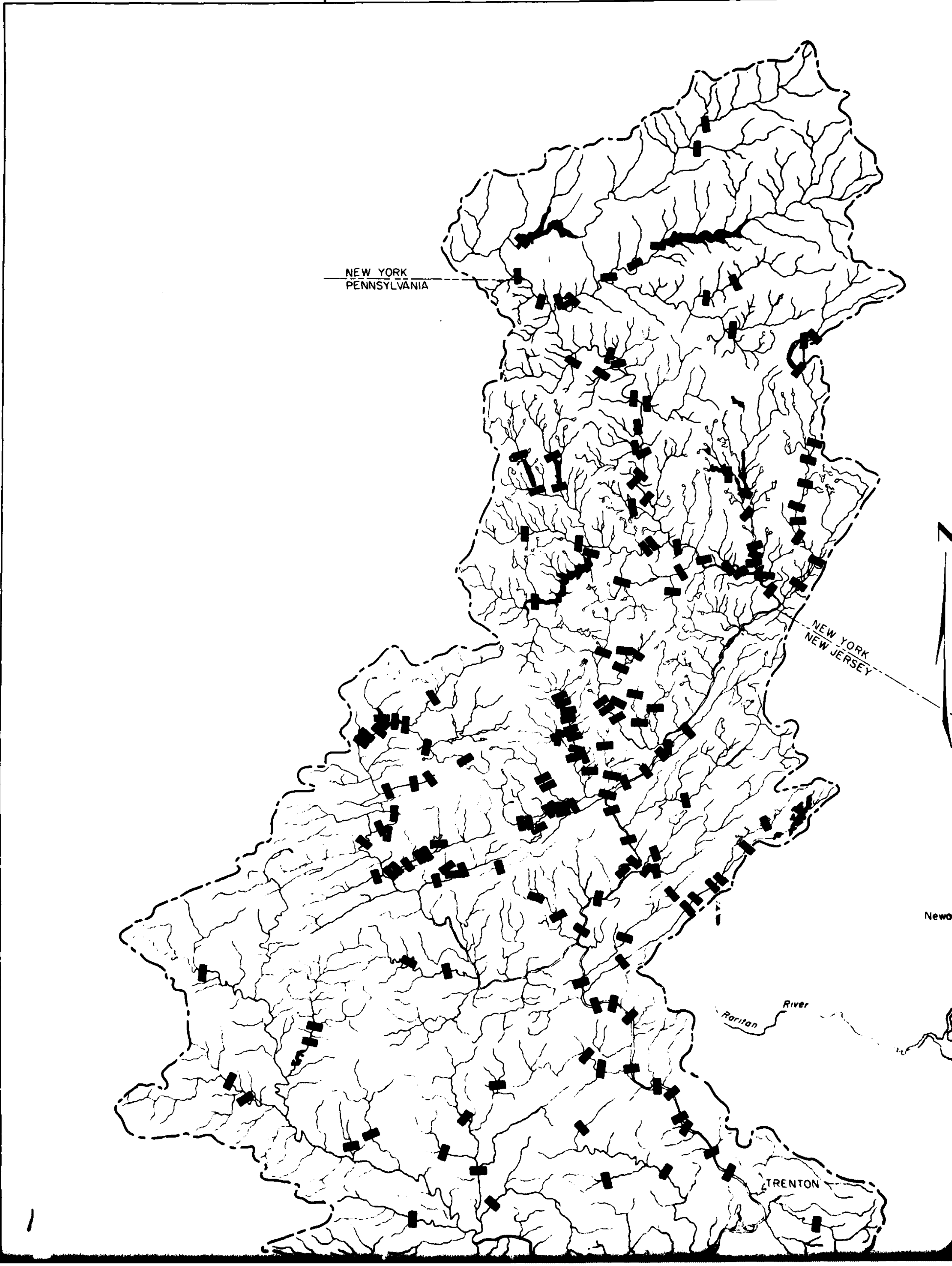
Scale as Shown
Philadelphia District
23 Oct. 1959

Drawer No. 228

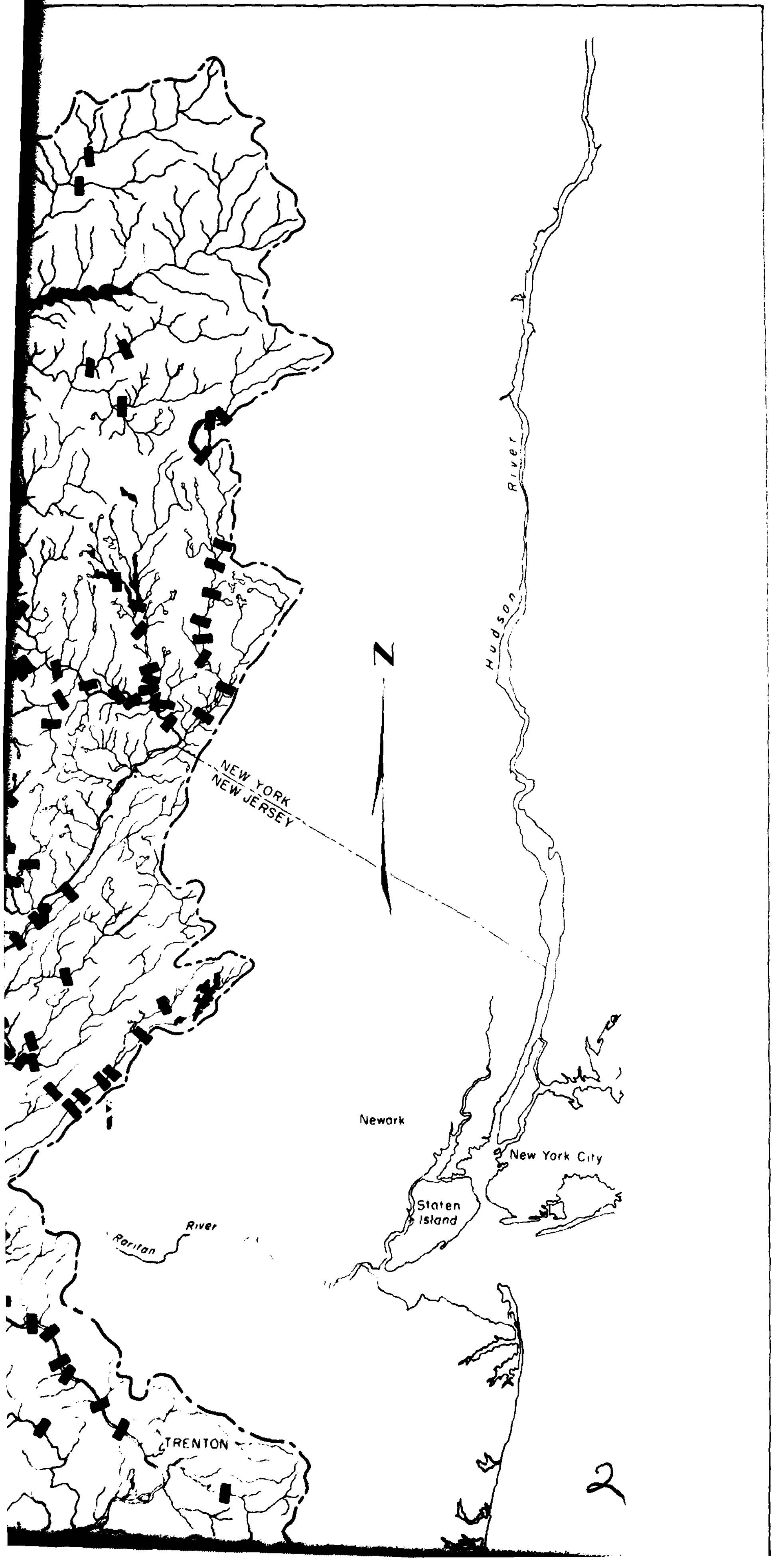
File No. 29079

PLATE 2

CORPS OF ENGINEERS



U.S. ARMY



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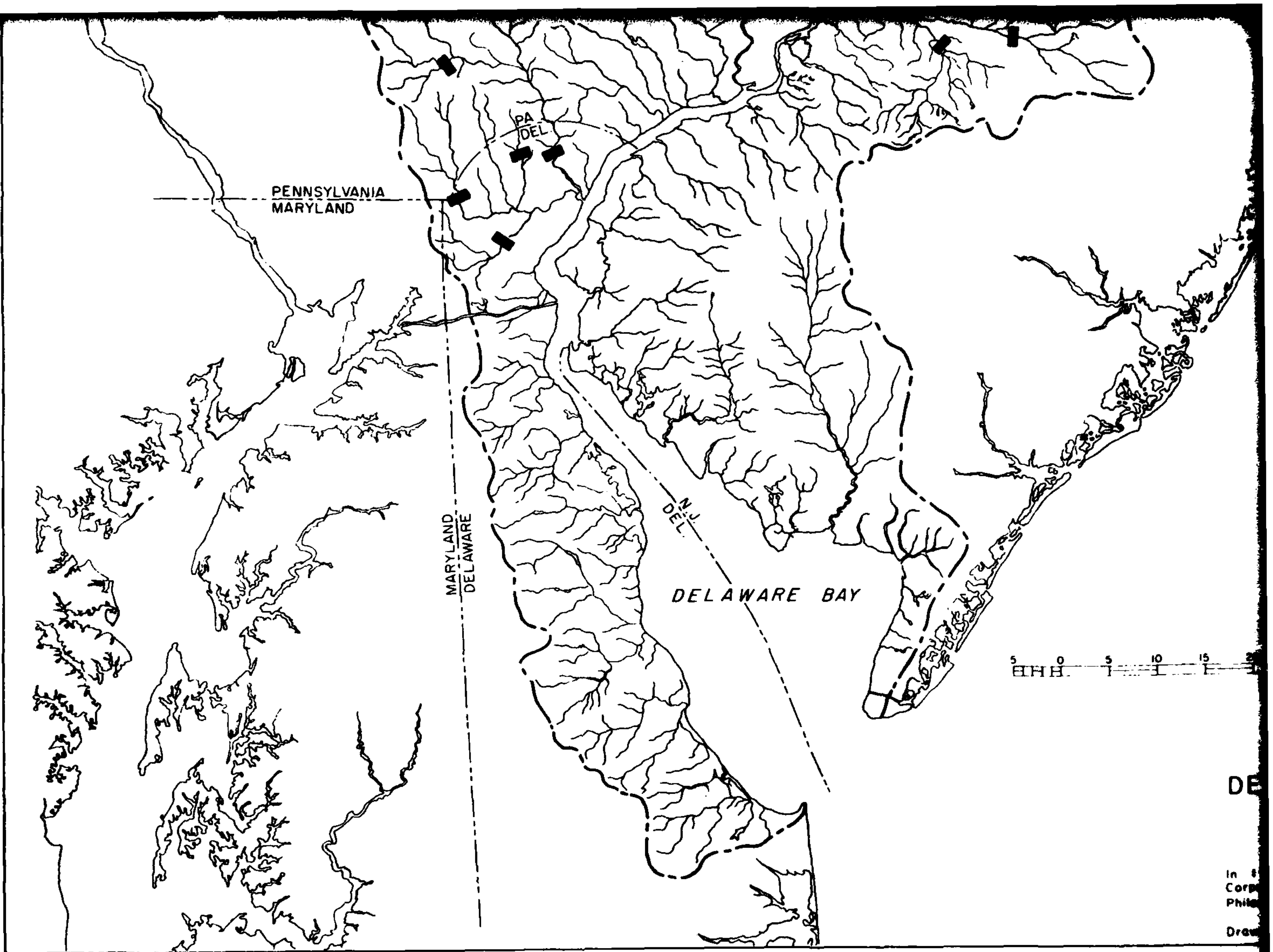
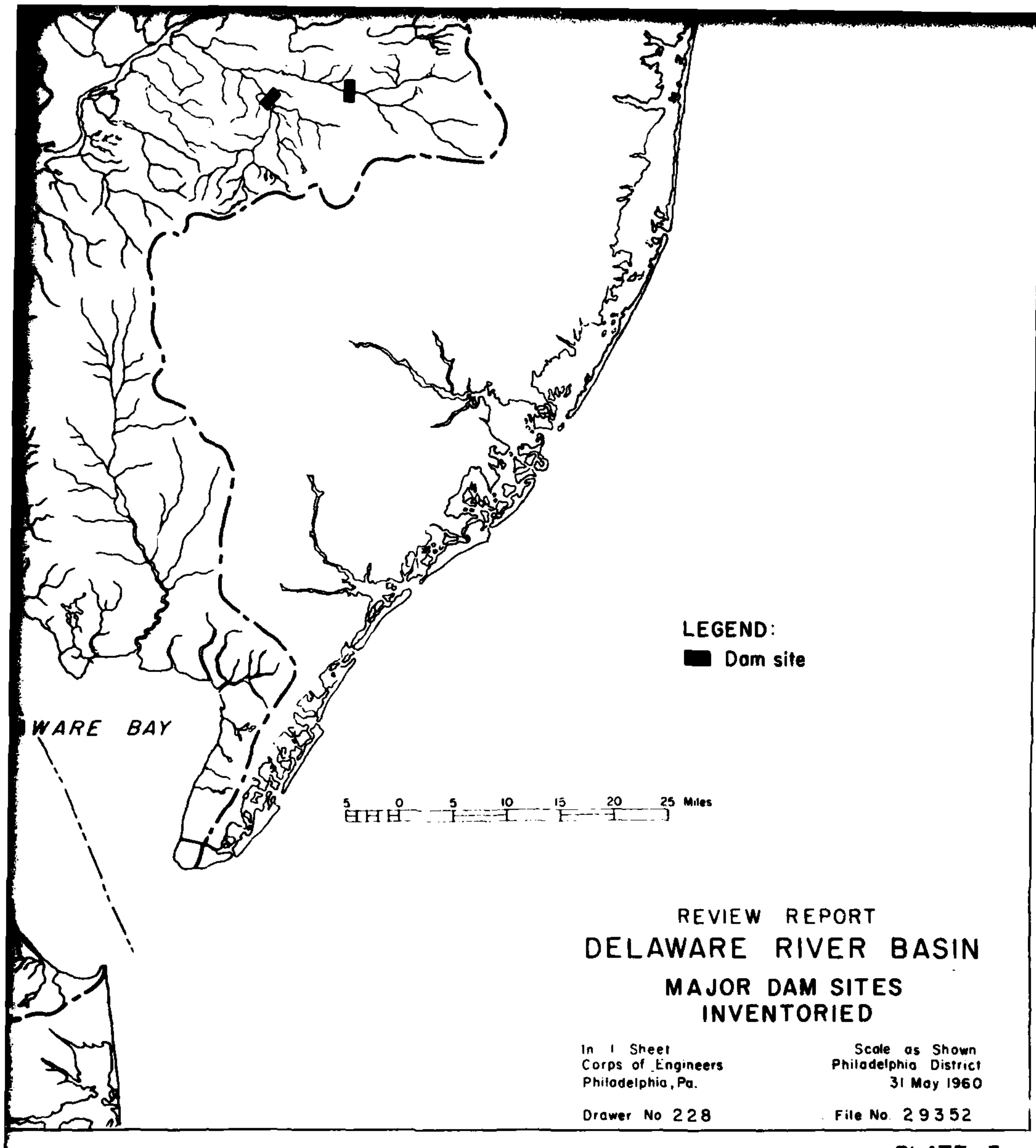
Hudson River
NEW YORK
NEW JERSEY
Newark
New York City
Staten Island
Raritan River
TRENTON

2


PENNSYLVANIA
MARYLAND
PA
DEL.
MARYLAND
DELAWARE
N.J.
DEL.
DELAWARE BAY
5 0 5 10 15

3



REVIEW REPORT
DELAWARE RIVER BASIN
MAJOR DAM SITES
INVENTORIED

In 1 Sheet
Corps of Engineers
Philadelphia, Pa.

Scale as Shown
Philadelphia District
31 May 1960

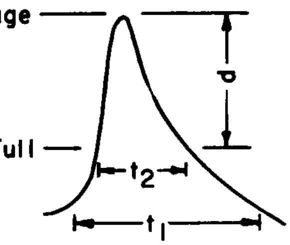
Drawer No 228

File No. 29352

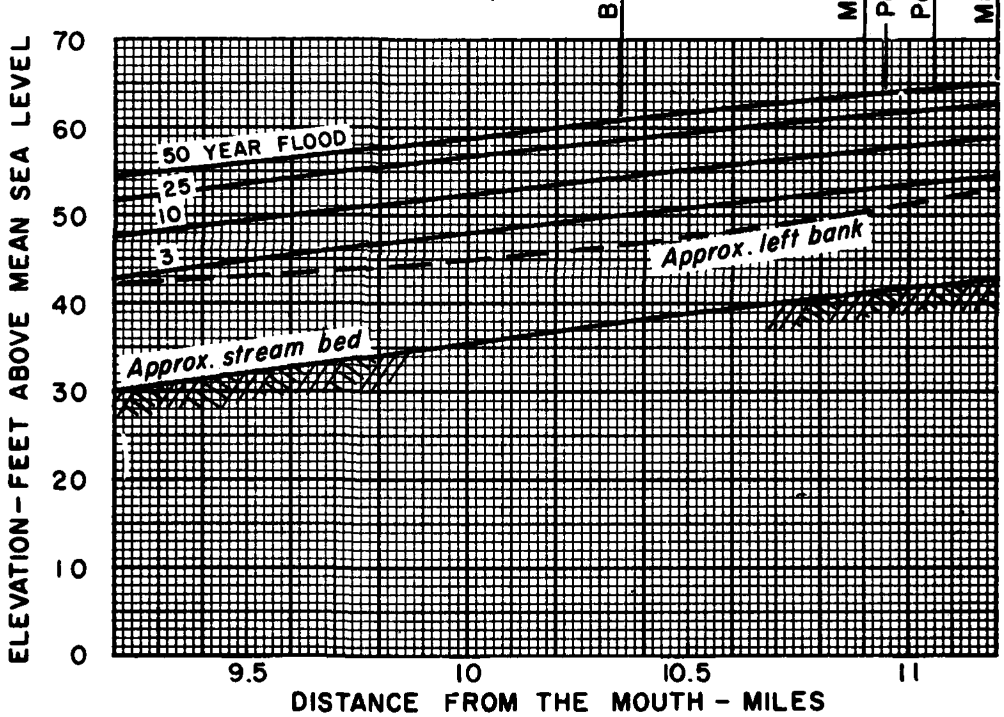
PLATE 3

4

50 YEAR FLOOD CHARACTERISTICS



Rate of rise	1.8 ft. per. hr.
Peak discharge	49,000 cfs
Duration of peak	2 hrs.
Duration of flooding, t_2	24 hrs.
Total duration, t_1	48 hrs.
Maximum inundation, d	14 ft.



REVIEW REPORT

DELAWARE RIVER BASIN

FLOOD PROFILES

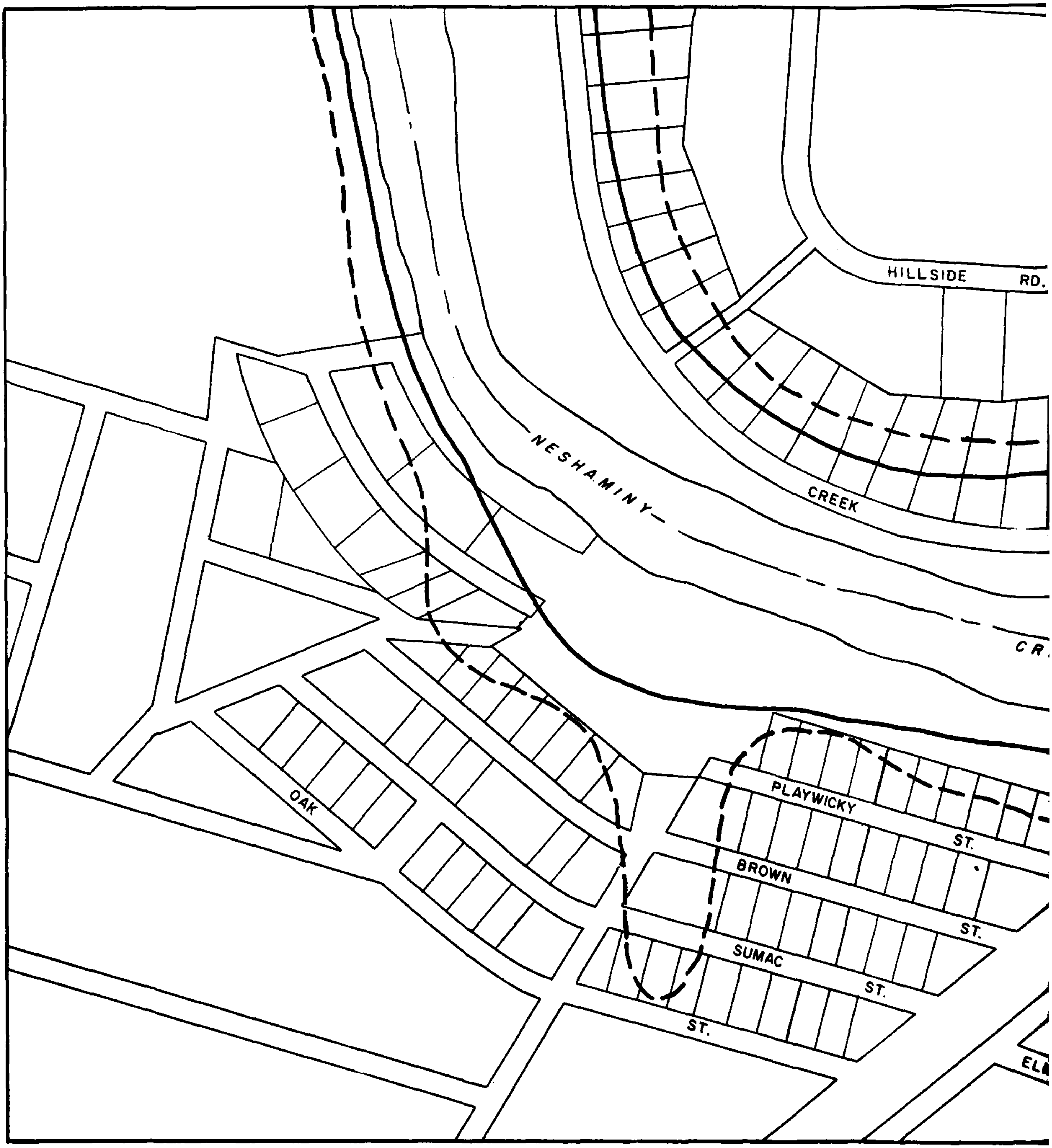
NESHAMINY CREEK

In 1 Sheet
Corps of Engineers
Philadelphia, Pa.

Scales as Shown
Philadelphia District
23 Oct. 19[illegible]

Drawer No 228

File No. 29354



HILLSIDE RD.
NESHAMINY
CREEK
CR
PLAYWICKY ST.
BROWN ST.
SUMAC ST.
OAK
ST.
EL

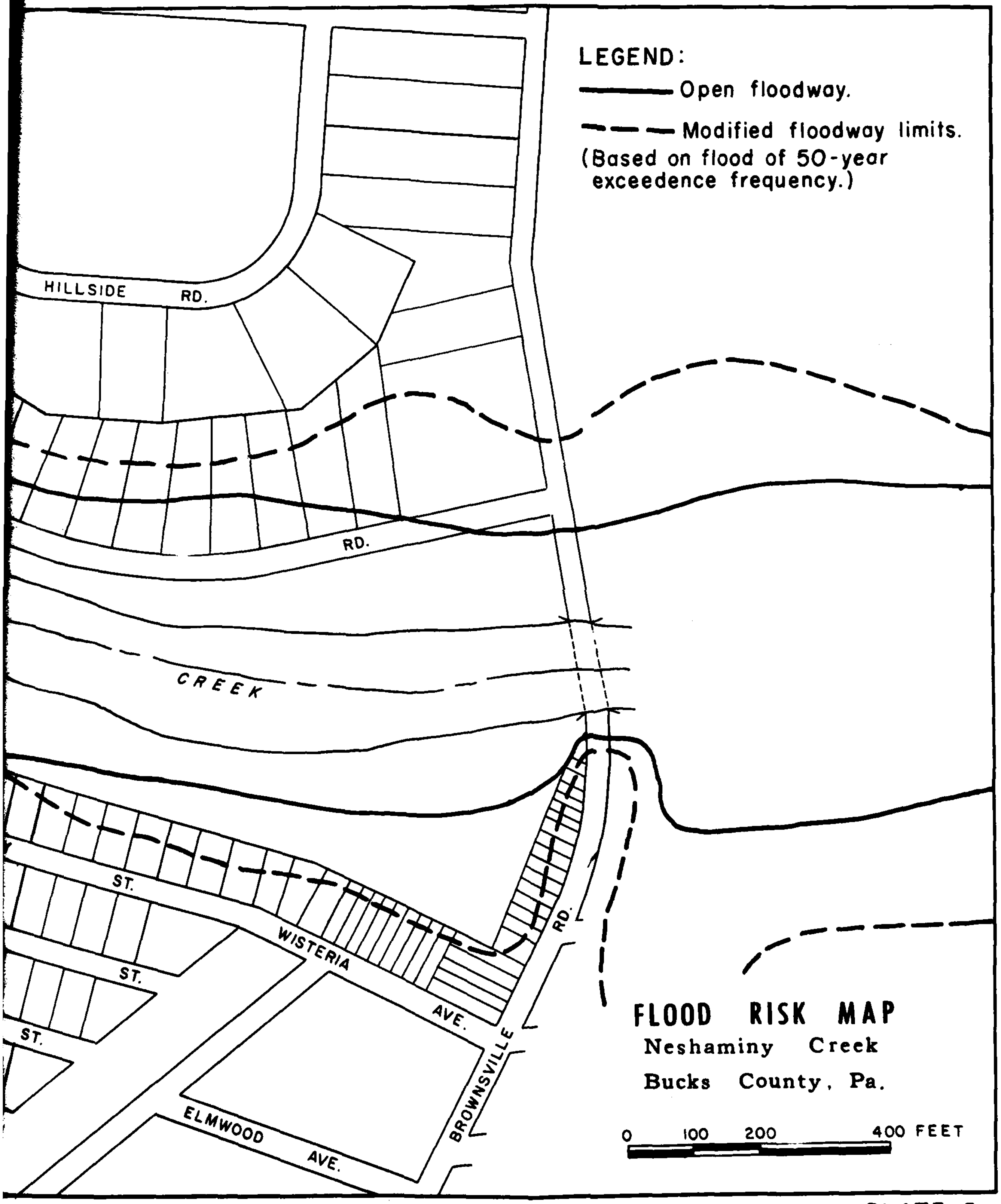

LEGEND:
Open floodway.
Modified floodway limits.
(Based on flood of 50-year exceedence frequency.)
HILLSIDE RD.
RD.
CREEK
ST.
ST.
ST.
WISTERIA AVE.
RD.
BROWNSVILLE
ELMWOOD AVE.
FLOOD RISK MAP
Neshaminy Creek
Bucks County, Pa.
0 100 200 400 FEET

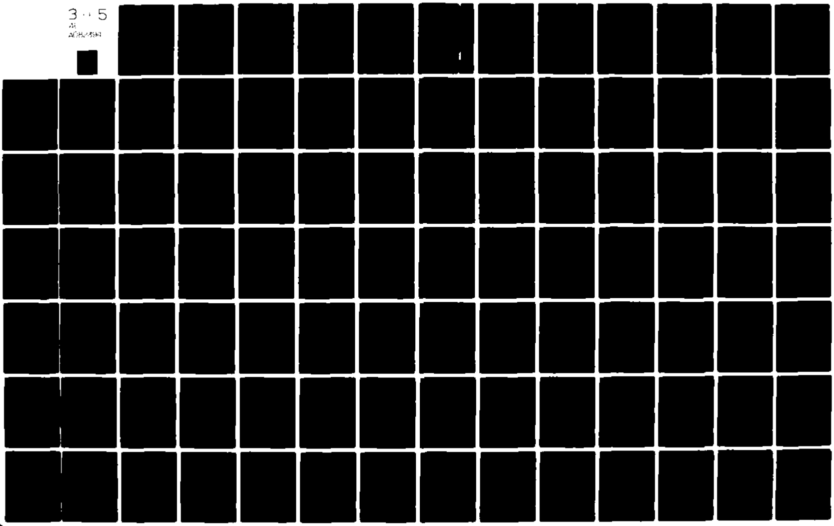
PLATE 5

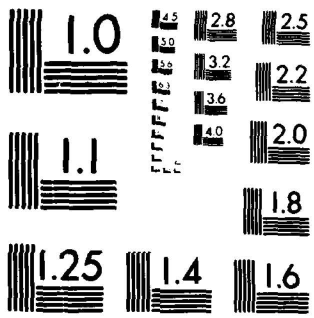
2

AD-A082 394 ARMY ENGINEER DISTRICT PHILADELPHIA PA F/G 13/2
REPORT ON THE COMPREHENSIVE SURVEY OF THE WATER RESOURCES OF TH--ETC(U)
DEC 60

UNCLASSIFIED NL

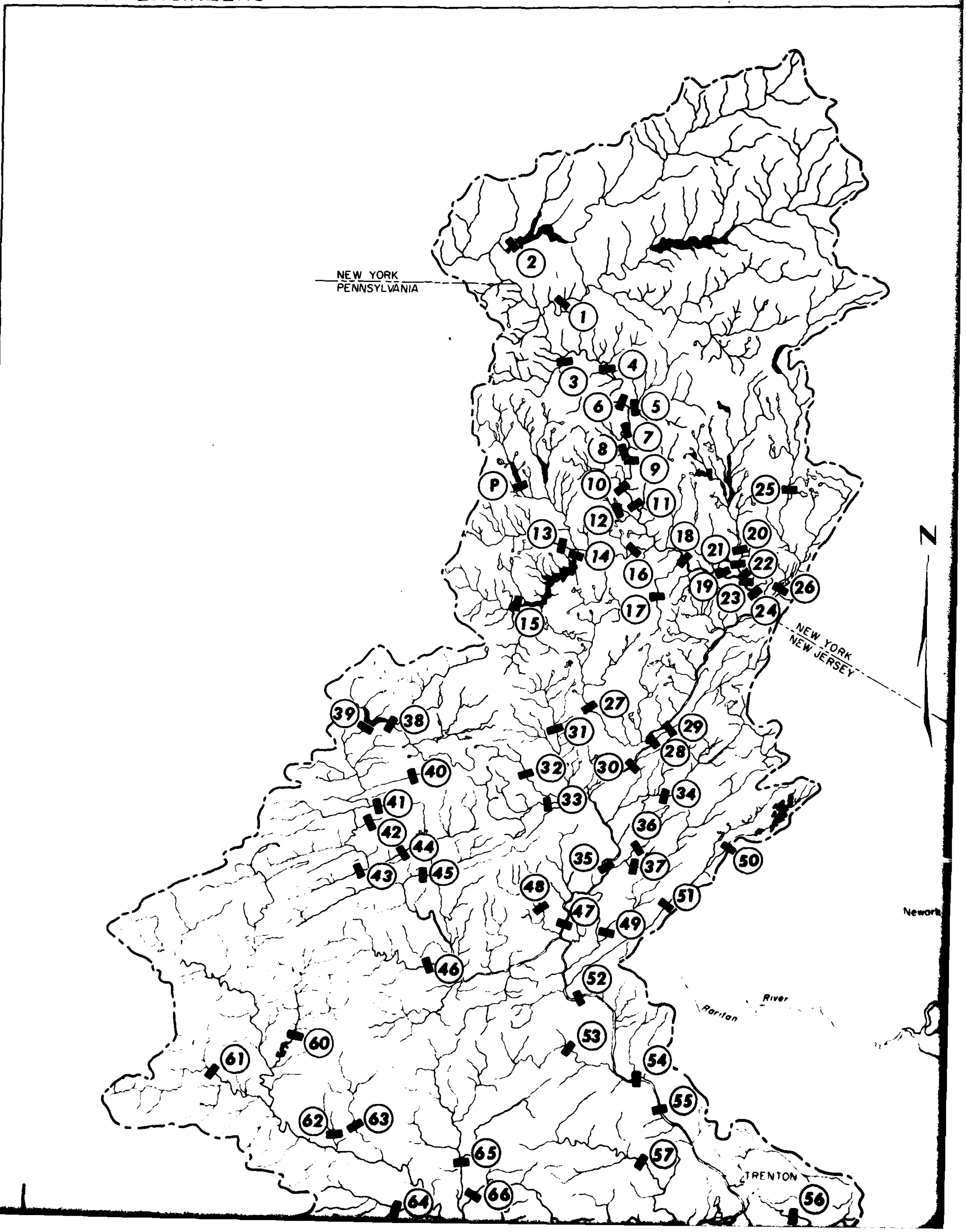
3 of 5

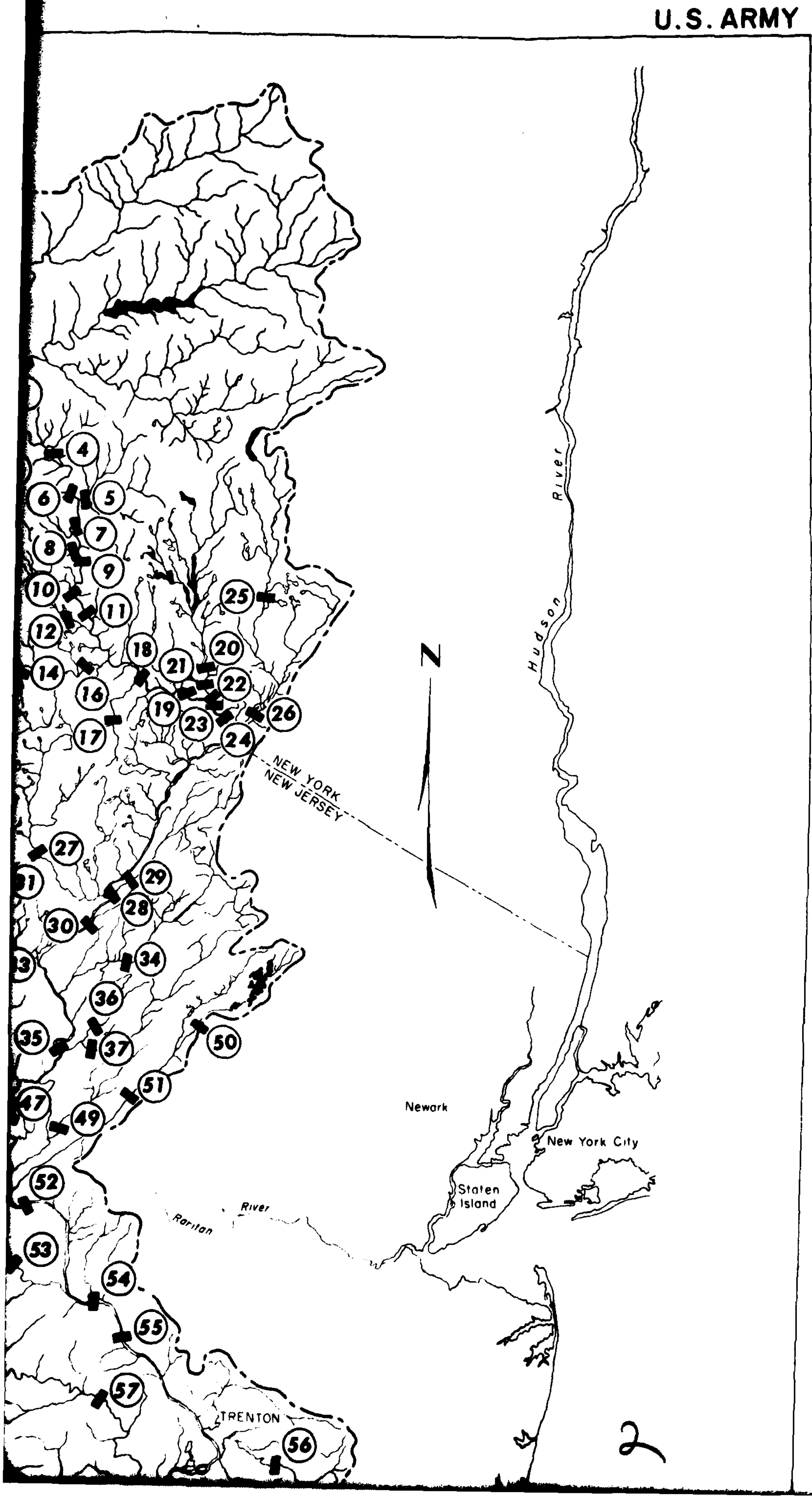




MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

CORPS OF ENGINEERS





U.S. ARMY
N
Hudson River
NEW YORK
NEW JERSEY
Newark
New York City
Staten Island
Raritan River
TRENTON
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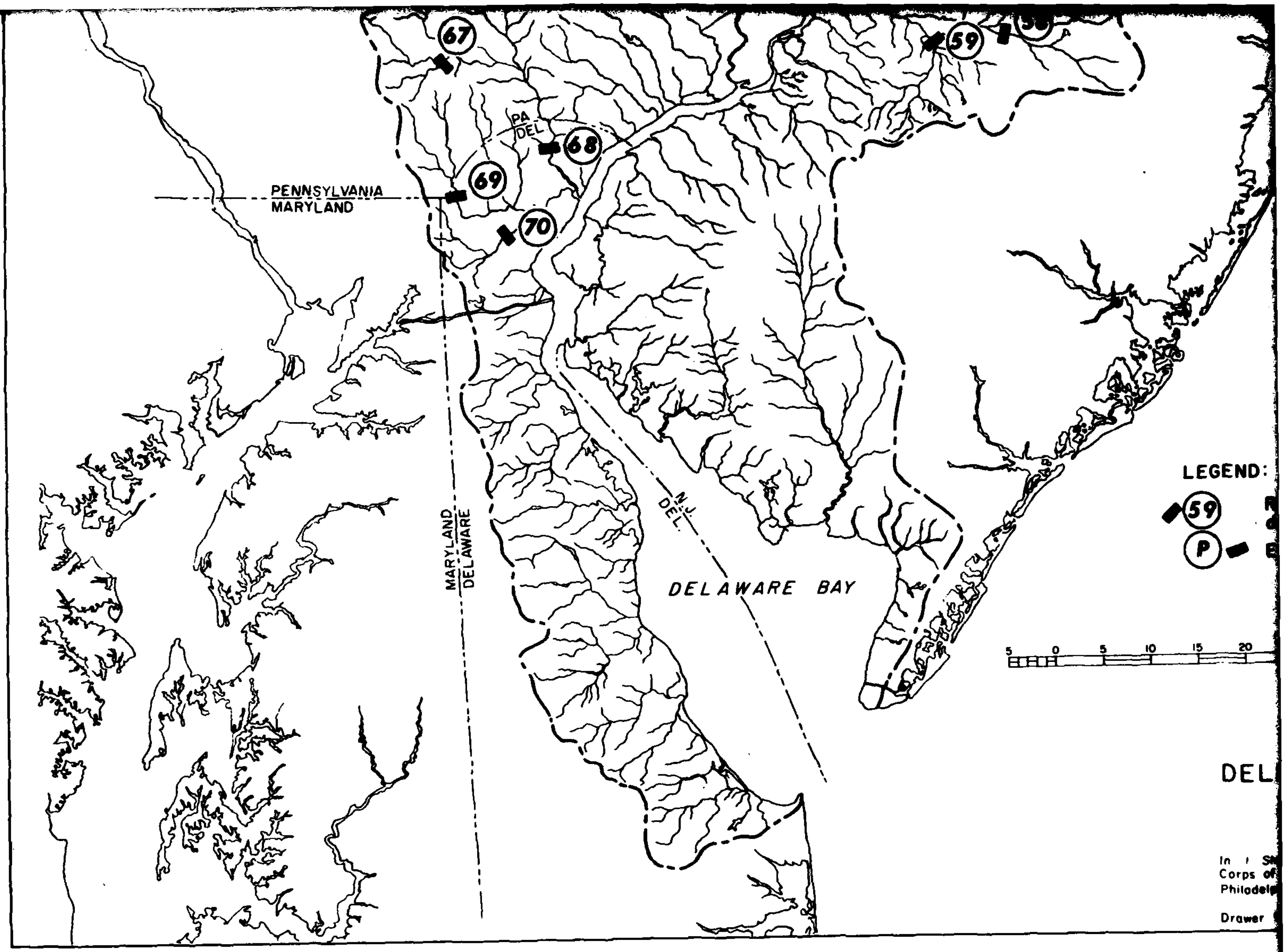
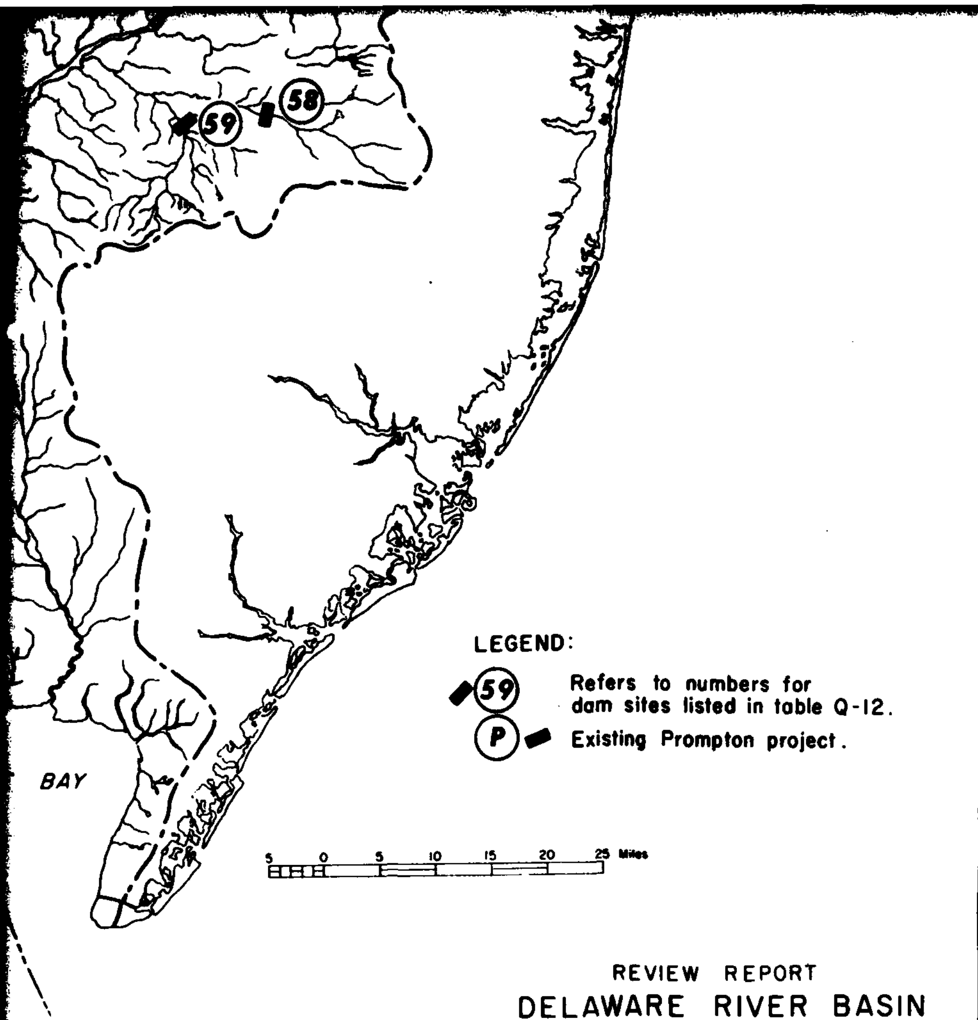

PENNSYLVANIA
MARYLAND
PA
DEL
MARYLAND
DELAWARE
N.J.
DEL.
DELAWARE BAY
LEGEND:
DEL
In
Corps of
Philadel
Drawer

3



REVIEW REPORT

DELAWARE RIVER BASIN

MAJOR DAM SITES INVESTIGATED

In 1 Sheet
Corps of Engineers
Philadelphia, Pa.

Scale as Shown
Philadelphia District
31 May 1960

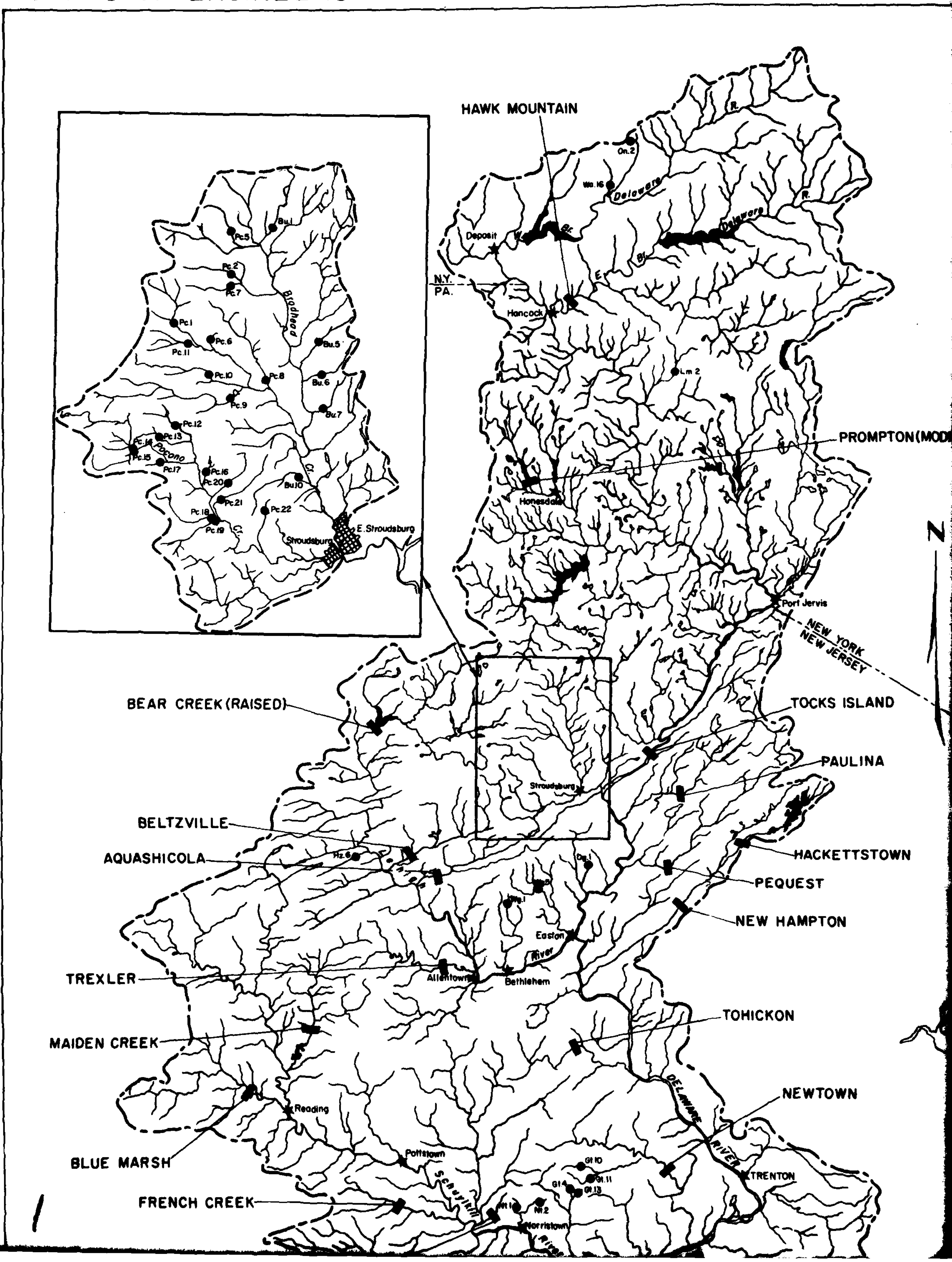
Drawer No 228

File No. 29351

PLATE 6

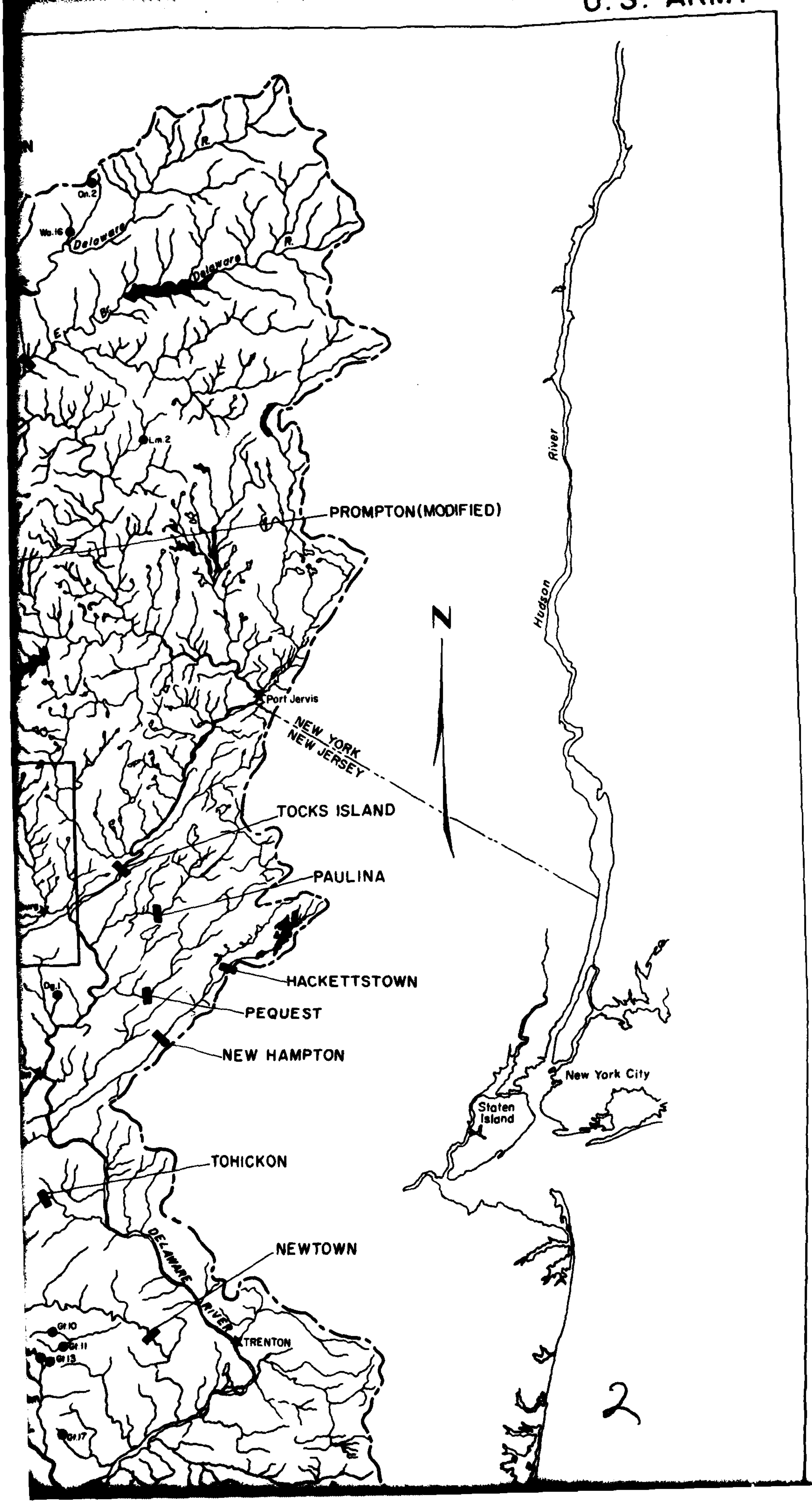
4

CORPS OF ENGINEERS



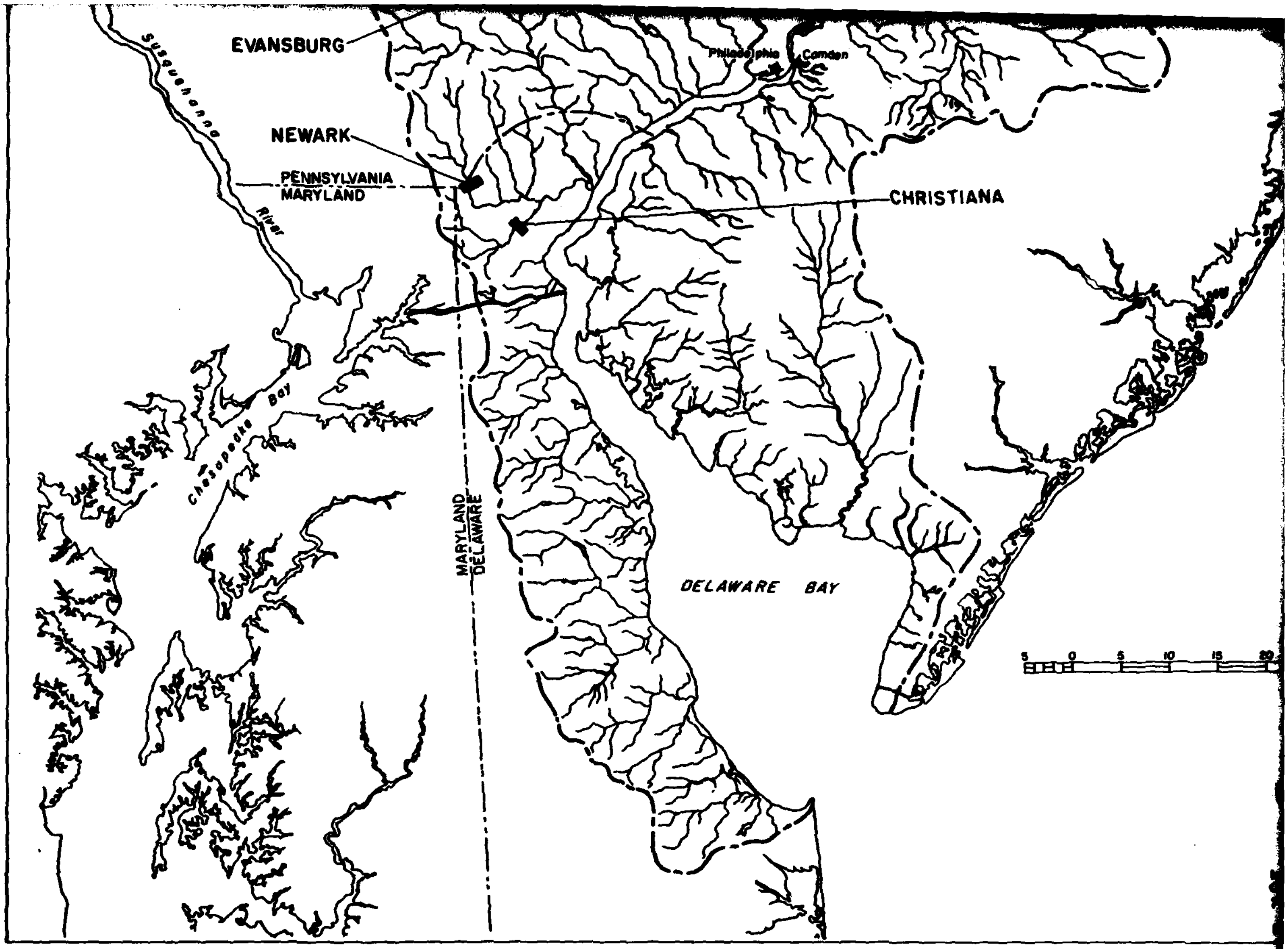
1

U.S. ARMY

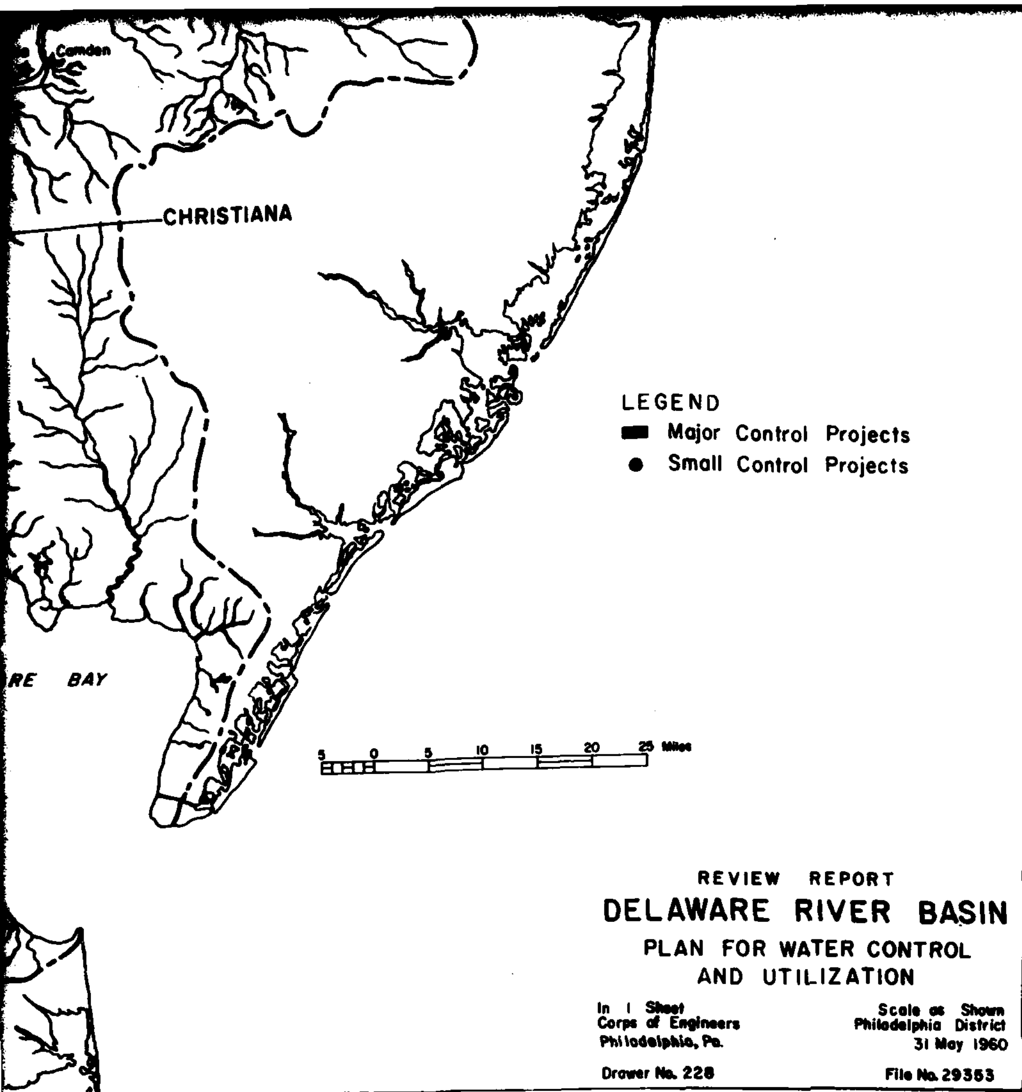


Delaware
R.
Delaware
R.
E. Br.
PROMPTON(MODIFIED)
N
River
Hudson
Port Jervis
NEW YORK
NEW JERSEY
TOCKS ISLAND
PAULINA
HACKETTSTOWN
PEQUEST
NEW HAMPTON
New York City
Staten Island
TOHICKON
NEWTOWN
DELAWARE RIVER
TRENTON

2


EVANSBURG
Philadelphia
Camden
NEWARK
PENNSYLVANIA
MARYLAND
CHRISTIANA
Susquehanna
River
Chesapeake Bay
MARYLAND
DELAWARE
DELAWARE BAY
5 0 5 10 15 20

3



REVIEW REPORT

DELAWARE RIVER BASIN

PLAN FOR WATER CONTROL AND UTILIZATION

In 1 Sheet
Corps of Engineers
Philadelphia, Pa.

Scale as Shown
Philadelphia District
31 May 1960

Drawer No. 228

File No. 29353

PLATE 7

4

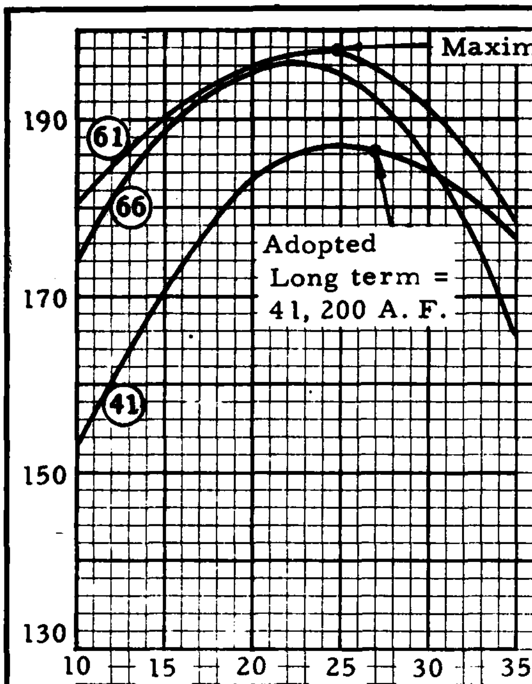


Fig. 1 BELTZVILLE

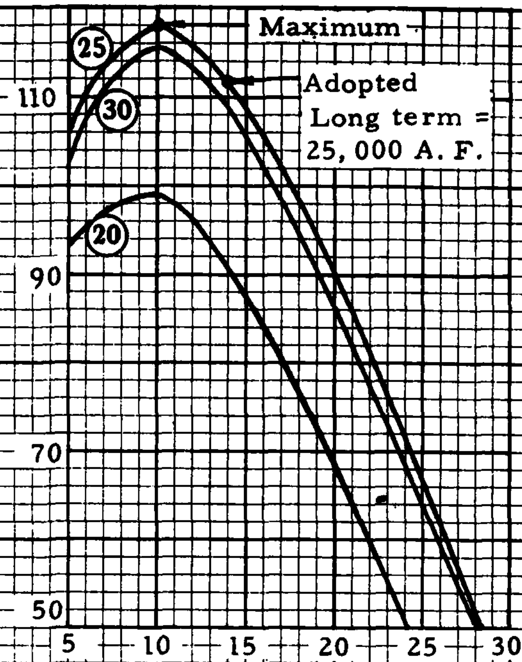


Fig. 2 TREXLER

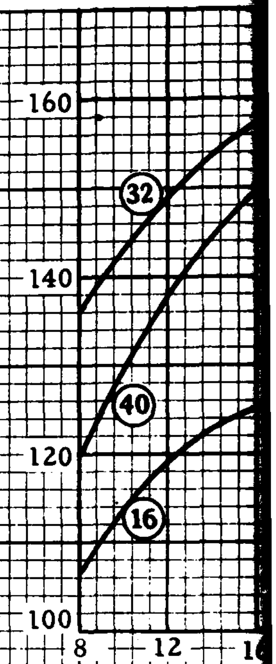


Fig. 3 AQUA

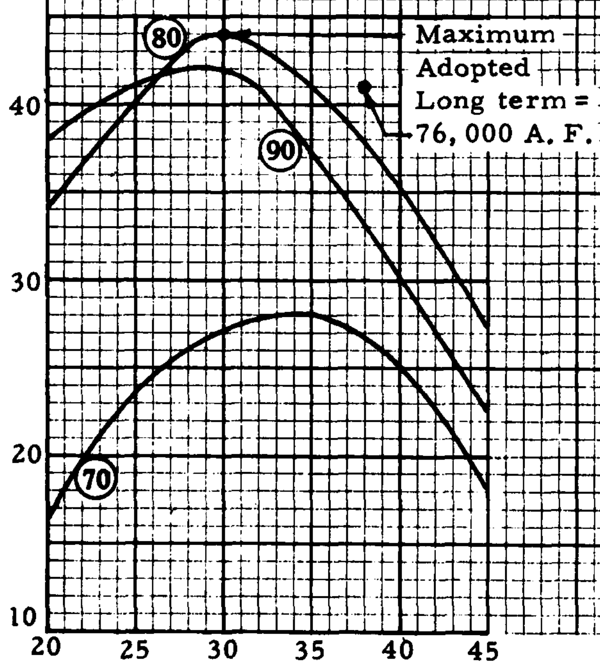


Fig. 5 MAIDEN CREEK

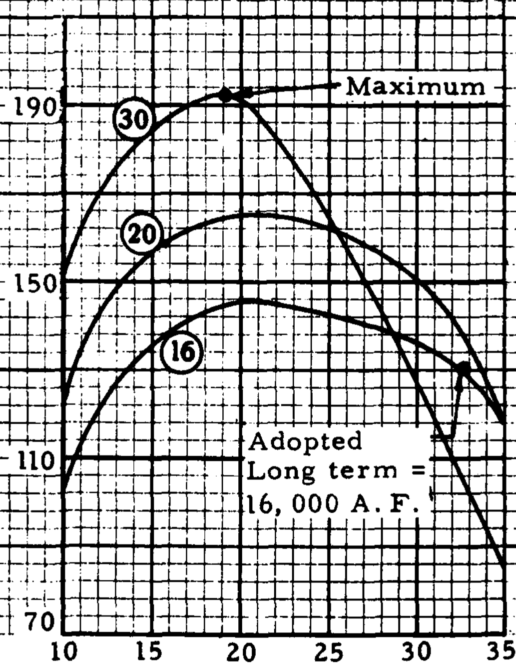


Fig. 6 BLUE MARSH

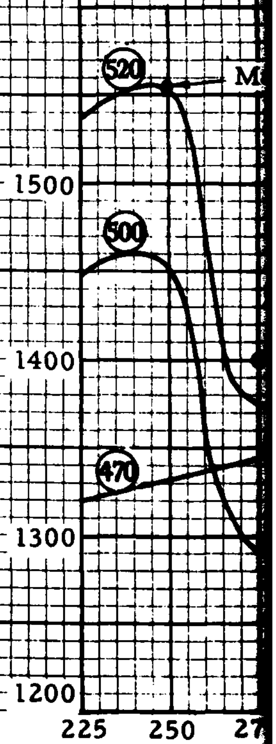
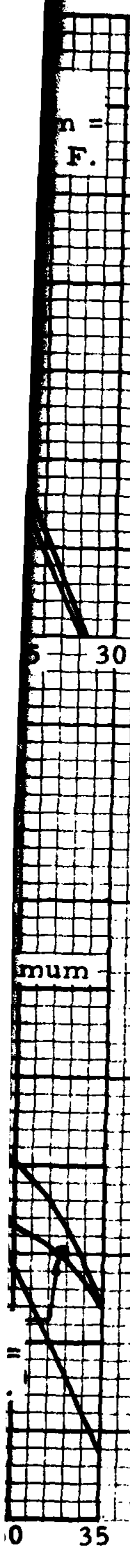


Fig. 7 TOC

U.S. ARMY



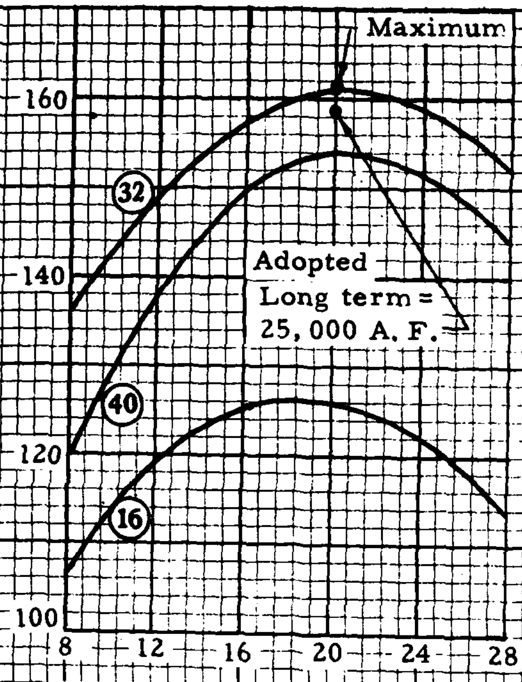


Fig. 3 AQUASHICOLA

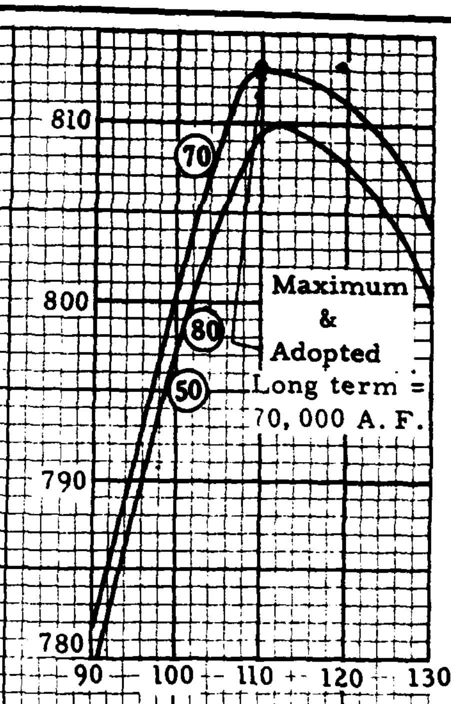


Fig. 4 BEAR CREEK

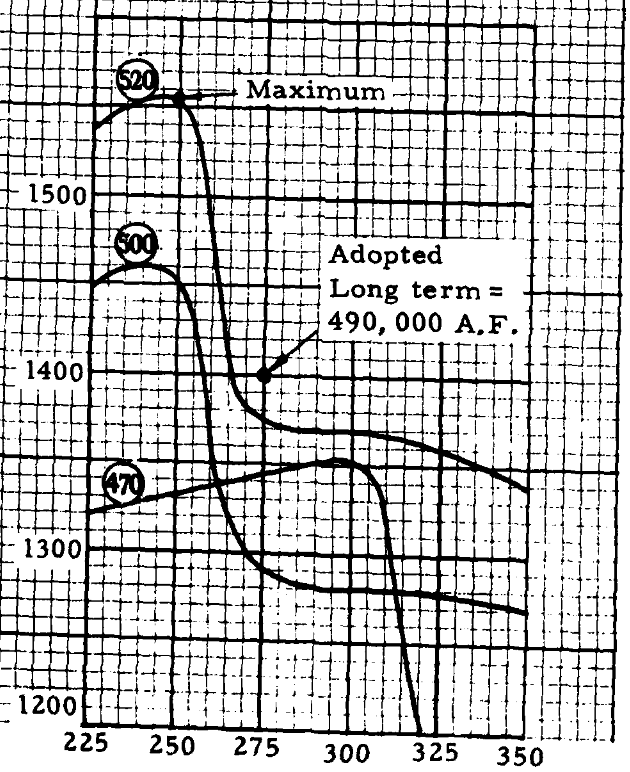


Fig. 7 TOCKS ISLAND

LEGEND:

(15) Designates long term storage allocation in 1000 acre feet.

All vertical scales --
NET BENEFITS ($1000)

All horizontal scales --
SHORT TERM STORAGE (1000 A.F.)

REVIEW REPORT
DELAWARE RIVER BASIN
MAXIMIZATION OF
NET BENEFITS FOR
INDIVIDUAL SITES

In 1 Sheet | Scales as shown
Corps of Engineers | Philadelphia District
Philadelphia, Pa. | 30 Dec. 1959

Drawer No. 228 | File No. 29355

PLATE 8

2

REPORT ON THE

COMPREHENSIVE SURVEY

OF

WATER RESOURCES

OF

DELAWARE RIVER BASIN

APPENDIX R

WATER CONTROL AT
INTERMEDIATE UPSTREAM LEVELS

PREPARED BY

CORPS OF ENGINEERS - SOIL CONSERVATION SERVICE
JOINT WORK GROUP

U. S. ARMY ENGINEER DISTRICT, PHILADELPHIA
CORPS OF ENGINEERS
PHILADELPHIA, PA.
JUNE 1960

C

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CONTENTS

SECTION V - COST ESTIMATES

C

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TABLES FOR APPENDIX R
(Tables follow the end of the text)

PLATES FOR APPENDIX R
(Plates follow the tables)

1. Location of Existing Public Law 566 Watersheds.
2. Typical Plan of a Small Dam.
3. Typical Section of a Small Dam.
4. Data Sheet - Reconnaissance of Headwater Dam and Reservoir Sites.
5. Location Map - 36 Sample Study Sites.
6. 293 Small Reservoir Sites.
7. Generalized Curves of Reservoir Sedimentation.
8. Areas of Similar Reservoir Sedimentation.
9. Spillway Design Storm Precipitation and Runoff for Small Reservoir Projects.
10. Problem Areas and Runoff Curve Numbers.
11. Sample Curves of Spillway Crest Length vs. Head and Discharge.
12. Unit Cost of Small Dams.
13. Generalized Curve of Drainage Area Controlled vs. Flood Damage Reduction.
14. Yield - Cost Relation.
15. Parkside Project (Pc 8).
16. Swiftwater Project (Pc 9).
17. Jim Thorpe Project (H_z 6).
18. 39 Proposed Projects.

APPENDIX R

WATER CONTROL AT INTERMEDIATE UPSTREAM LEVELS

1 INTRODUCTION

1. SCOPE. In defining the optimum plan for the control and utilization of the water resources of the Delaware River basin consideration has been given to all types of potential measures and engineering works. In progressive order from the point where the rain falls on the surface of the basin until it finds its way, by rivulets, creeks and the main stream, to the sea, these measures and works include land treatment measures, small dams and reservoirs and other engineering measures, major dams and reservoirs and other engineering works. The land treatment measures, the major dams and reservoirs, and engineering works are treated elsewhere in this report. The potentials of the small dams and reservoirs and other engineering measures at the intermediate level of development have been appraised and are reported on herein. Included are information and detailed data used for establishment of planning procedures, design criteria, cost estimates, and methods for evaluating hydrologic and economic effects of small reservoirs. Also, presented is an economic appraisal of individual projects with regard to providing the necessary goods and services for local problem areas. The economic appraisal and water development potential for groups of reservoir projects by watershed are presented for use as a basis for their integration into the formulation of a plan of improvement for the entire Delaware River basin as reported on in Appendix Q.

2. EXISTING PROGRAMS. Programs are already under way to provide small reservoirs and other engineering measures in the basin. The planning, design and construction of the small dam and reservoir projects may be accomplished by non-Federal interests such as states, counties, municipalities and private organizations and by Federal agencies such as the Soil Conservation Service or the Corps of Engineers. The Federal agencies, by various public laws, have been authorized by Congress to plan, design, construct and under certain conditions operate small reservoir projects either wholly or in part by Federal funds through the Secretary of Agriculture for the Soil Conservation Service and the Secretary of the Army for the Corps of Engineers. The various public laws under which the two agencies are now operating are discussed in the following paragraphs.

3. Flood Control Act of 1948. The Flood Control Act of 1948 (Public Law 858, 80th Congress), approved 30 June 1948, and as

subsequently amended by Flood Control Acts of 1950 and 1956 (Public Law) 516, 81st Congress and Public Law 685, 84th Congress, respectively), authorizes the Secretary of the Army "to allot from any appropriations heretofore or hereafter made for flood control, not to exceed $10,000,000 for any one fiscal year, for the construction of small flood control projects not specifically authorized by Congress, and not within areas intended to be protected by projects so authorized, which come within the provisions of section 1 of the Flood Control Act of 22 June 1936, when in the opinion of the Chief of Engineers such work is advisable: Provided, That not more than $400,000 shall be allotted for this purpose at any single locality from the appropriations for any one fiscal year: Provided further, That the provisions of local cooperation specified in section 3 of the Flood Control Act of 22 June 1936, as amended, shall apply: And provided further, That the work shall be complete in itself and not commit the United States to any additional improvement to insure its successful operation, except as may result from the normal procedure applying to projects authorized after submission of preliminary examination and survey reports."

4. Watershed Protection and Flood Prevention Act. The Congress of the United States enacted the Watershed Protection and Flood Prevention Act (Public Law 566, 83d Congress, as amended). This act authorizes the Secretary of Agriculture to cooperate with states and local agencies in the planning and carrying out of works of improvement for the prevention of damages of erosion, floodwater, and sediment and for furthering the conservation, development, utilization, and disposal of water. Responsibility for initiating projects under the act rests wholly with local people through local organizations having authority under state laws to carry out, maintain, and operate works of improvement. The local organizations must acquire without cost to the Federal Government all necessary land, easements, and rights of way, defray the costs of operating and maintaining the works of improvement; let all contracts for construction of works of improvement on non-Federal lands; obtain water rights; assume part of the costs of irrigation, drainage, and fish and wildlife measures; bear all of the costs for measures serving nonagricultural purposes; and obtain agreements from owners of at least 50 percent of the lands in the watershed above each retention reservoir to carry out recommended soil conservation measures. The Secretary of Agriculture may provide local organizations with technical, financial, and credit assistance in planning and installing needed water management and flood prevention measures. The planning is limited to water sheds or subwatershed areas of 250,000 acres or less and to individual reservoirs with a maximum total capacity of 25,000 acre-feet and maximum floodwater detention capacity of 5,000 acre-feet. In the event that the estimated Federal contribution to construction costs exceeds $250,000, or the plan provides for structures with a capacity greater than 2,500 acre-feet but less than 4,000 acre-feet in a single structure, it must be approved by resolutions of the Committee on

Agriculture and Forestry of the U. S. Senate and the Committee on Agriculture of the U. S. House of Representatives. Any plan involving a single structure of more than 4,000 acre-feet of total capacity must be approved by resolutions of the Committees on Public Works of the Senate and House of Representatives. Section 6 of the Act authorizes the Department of Agriculture to cooperate with other Federal and with state and local agencies to make investigations and surveys of watersheds of rivers and other waterways as a basis for the development of coordinated programs.

5. State Legislation. The four states (Pennsylvania, New York, New Jersey and Delaware) have enacted legislation for implementing Public Law 566, Watershed Protection and Flood Prevention Act, within each state. All four states will permit designated local organizations to participate to the extent required by Public Law 566. The extent to which local organizations and the state are empowered to participate beyond that required by Public Law 566 varies from state to state.

6. Corps of Engineers' Program. Under existing authority the Corps of Engineers can, upon request from local interests, plan and design small reservoir projects. The field investigations, plans and design of these projects are carried out by the District Engineer, and he determines the justification for each individual project in accordance with established criteria and procedures. If findings are favorable he can recommend construction of a project to the Chief of Engineers. If, upon review by the Chief of Engineers, the project is deemed advisable, allocation of funds within the limitations established by the 1948 Flood Control Act is then made for its construction.

7. Assistance Provided by the Soil Conservation Service in Watershed Protection and Flood Prevention. Applications from local organizations for assistance in planning and carrying out a watershed project under the provisions of Public Law 566 must first be approved by the state agency having supervisory responsibility or the Governor of the state if there is no such agency. The application is then submitted to the Secretary of Agriculture. When planning assistance is authorized, assistance is provided to local organizations to help develop a watershed work plan and the completed plan must be approved by the Administrator of the Soil Conservation Service, acting for the Secretary of Agriculture, and by Congressional Committees under the conditions cited in paragraph 4. After this approval, assistance may be made available to the local organizations to install the works of improvement in accordance with the approved work plan.

8. JOINT WORK GROUP. The appraisal of the small dams and watershed measures, as necessary elements of the comprehensive plan for the control and utilization of the water resources of the Delaware River basin, required procedures whereby the overlapping legal and resources

management responsibilities of the Corps of Engineers and the Soil Conservation Service would be integrated by a partnership approach to the task. Accordingly a Joint Work Group capable of actively pursuing such procedures was established to provide the material contained herein to serve as a source of information and guidance in the formulation of the comprehensive plan.

9. Group Organization. The Joint Work Group was established at field level and consisted of two representatives of the Soil Conservation Service and two representatives of the Corps of Engineers. The members of the Joint Work Group were designated by the officials in administrative charge of the Engineering and Watershed Planning Unit, Soil Conservation Service, Upper Darby, Pennsylvania, and Valley Report Group, U. S. Engineer District, Philadelphia, to perform and direct the necessary work for the development and evaluation of small reservoir sites as a part of the comprehensive survey of the water resources of the Delaware River basin. It was realized that an informal joint effort by the two agencies in the study and preparation of this appendix covering small dams and watershed measures would permit optimum treatment of many detailed and complex problems that could not be anticipated and resolved by a formal agreement of mutual understanding. In order to provide a good informal working arrangement it was agreed that the minutes of the meetings of the Joint Work Group would serve to record the agreements reached and procedures adopted for the work, the nature and extent of the investigations to be made for upstream reservoirs, and the criteria and other factors governing the design and economic appraisal of such reservoirs. Copies of these minutes are in the files of the offices of the two agencies represented on the Joint Work Group.

10. Group Assignments. Basic assignments were made to the two agencies for major items of work and for the preparation of major segments of this appendix with the understanding that the agency with a specific assignment should call on personnel of the other agency for assistance in covering specialties within the major segments. The final appendix, however, was reviewed by all members of the Joint Work Group and is considered a joint effort even though the original authorship of individual segments was assigned to either agency. The basic assignments for preparation of this appendix were as follows:

I	INTRODUCTION	CE 1/
II	BASIN PROBLEMS	CE
III	PLANNING PROCEDURES	SCS 2/
IV	DESIGN CRITERIA	SCS & CE
V	COST ESTIMATES	SCS & CE
VI	METHODS OF EVALUATING HYDROLOGIC AND ECONOMIC EFFECTS	SCS

VII	ECONOMIC APPRAISALS AND WATER DEVELOPMENT POTENTIAL	CE & SCS
VIII	ROLE OF UPSTREAM AUXILIARY RESERVOIRS IN THE INTEGRATED PLAN FOR COMPREHENSIVE DEVELOPMENT OF WATER RESOURCES IN THE DELAWARE RIVER BASIN	CE & SCS

11. STATUS OF CURRENT PROGRAMS. Flood control measures in the intermediate level of development, including dams and reservoirs, levees and flood walls, channel rectification and debris clearances, have been planned, constructed or are under construction through Federal, state or local programs. The status of the work of these local flood protection projects in the Delaware River basin is as follows:

a. Federal Program. Projects completed or under construction are located on tributaries to Lackawaxen River between Honesdale and Hawley, Pennsylvania, Pequest River near Great Meadows, New Jersey, Rancocas Creek at Mt. Holly, New Jersey, and Chester River in Chester, Pennsylvania. Planning studies have been completed to determine the feasibility of individual local flood protection projects at the following locations: Little Beaverkill and Willowemoc Creek at Livingston Manor, New York, Beaverkill at Roscoe and Rockland, New York, Neversink River at Godeffroy, New York, Little Schuylkill River at Tamaqua, Pennsylvania, Stony Creek and Saw Mill Run at Norristown, Pennsylvania, West Brandywine Creek at Coatesville, Pennsylvania, and Mill Creek near Wilmington, Delaware. There are nine watershed associations located in the basin which have received authorization for Federal planning assistance. These watershed associations are: Lackawaxen, Pennsylvania, Greene-Dreher, Pennsylvania, Brodhead, Pennsylvania, Little Schuylkill, Pennsylvania, Brandywine, Pennsylvania and Delaware, Pequest, New Jersey, Paulins Kill, New Jersey, Town Bank, New Jersey, and Pine Mountain Creek (Cumberland County), New Jersey. Watershed work plans have been prepared for six of these tributary basins as outlined in plate 1. The effects of the small dam and reservoir projects as designated in the work plans are taken into consideration in the formulation of the comprehensive plan presented in Appendix Q.

b. State Program. The Commonwealth of Pennsylvania, Department of Forests and Waters, undertook 163 emergency stream clearance projects in the Delaware River basin following the disastrous floods of August 1955. These operations included 123 channel rectification projects and 40 debris removal projects at an approximate cost of $1,600,000. The state also completed a permanent flood

1/ U. S. Engineer District, Philadelphia
2/ Soil Conservation Service

protection project on the Lehigh River at Weissport, Carbon County, at a construction cost of $81,300. By 1 July 1960 three local protection projects, at an estimated construction cost of $2,325,000, will be under construction on Middle Creek and the Lackawaxen River at Hawley, Wayne County; Lollipop Creek at White Mills, Wayne County; and Brodhead and McMichael Creeks, in Stroudsburg and East Stroudsburg, Monroe County.

12. GENERAL DEFINITIONS. The Joint Work Group adopted the following definitions for use in this investigation:

a. Upstream Reservoirs. Upstream dams and reservoirs, also referred to in this appendix as small dams and reservoirs, are located in the upper watersheds of tributary streams, with the following limitations placed on controlled drainage area and storage capacity.

Drainage Area: Greater than one square mile.

Storage Capacity of the Reservoir: Four inches or more of runoff from the drainage area.

b. Spillway. The broad crested, uncontrolled channel near the top of the dam for the passage of surplus floodwater.

c. Outlet. The conduit, or conduits, complete with control equipment, trashrack, etc., provided to carry water under or around the dam at an elevation lower than the spillway. In small dams the outlet will be a pipe (or pipes) beneath the dam with a single riser in the reservoir for entrance of the water. The top of the riser is provided with a vortex-suppression device and a trashrack; but there shall be no control or hindrance to the free flow of water into the riser at the top. Near the bottom of the riser there will be a slide gate for the controlled entrance of water into the outlet when the water surface in the reservoir is below the top of the riser.

d. Reservoir Full Pool Elevation. Elevation of the reservoir surface when the reservoir is filled to the spillway crest.

e. Maximum Reservoir Elevation. Full pool elevation plus the height required to pass the spillway design flood through the spillway, with all outlets open.

f. Reservoir Depth. The difference between full pool elevation and stream bed elevation, measured at the axis of the dam site.

g. Reservoir Area. Surface area of the reservoir in acres, measured at full pool elevation.

h. Reservoir Capacity. Capacity of the reservoir at full pool elevation, usually given in acre-feet. Except where otherwise indicated, this was calculated for initial estimating purposes as 0.4 of the reservoir area times the reservoir depth.

i. Conservation Storage. Reservoir space other than that intended for sedimentation and flood control allocated to uses such as low flow augmentation, water supply, and recreation.

j. Height of Dam. Vertical distance measured from the stream bed at the axis of the dam site to the top of the dam.

k. Freeboard. Vertical distance between the maximum reservoir elevation and top of dam.

13. MEASURES CONSIDERED. Such engineering measures for flood control as small dams and reservoirs, levees, flood walls, drainage, channel rectification, snagging and channel cleanout have been investigated under the current program described above for localities where local interests have expressed desires for such measures or where such measures appeared to merit study. The means are available under existing authorities to reexamine or extend studies of these types as the need arises. However, the definition of a comprehensive plan in terms of basic storage facilities required an investigation of the potentials and needs that must be satisfied by storage opportunities at the level of the small dam and reservoir. Future facilities in this area of planning, outlined in the following paragraphs, are associated with local needs for flood control, local water supply, recreation and fishing and hunting needs, and low flow regulation. An example of the small dam structure under consideration here is shown on plates 2 and 3.

SECTION II - BASIN PROBLEMS

14. <u>GENERAL MARKET PROBLEMS FOR UPSTREAM RESERVOIRS</u>. A basic requirement in the formulation of any plan of development is the availability of markets for all the goods and services produced by each element in the plan of development. The goods and services referred to are flood control, water supply, hydropower, irrigation, recreation, fish and game opportunities, water transportation, and low flow regulation. The goods and services resulting from the plan for the development of water resources can also be provided for by alternate means and to varying degrees depending upon the geographical location of projects. This results in extended and complex problems when considering an entire river basin such as the Delaware. It is apparent that major control reservoirs cannot fully satisfy all of the markets because of geographic and physical constraints inherent in this type of development and the need to locate developments with relation to the upstream problem areas which they serve. Therefore, the investigation of small upstream reservoir projects provides a basis for satisfying the needs for water resources goods and services at a local level of demand. In addition the small reservoir will provide an auxiliary means to satisfy a portion of the goods and services for the general market of water resources throughout the entire basin.

15. <u>Definition of Problem Areas for Satisfying Local Markets</u>. To define the local markets for the several products available from water resources development, it was first necessary to determine the problem areas for the individual goods and services required. The detailed nature and extent of any one of the vast number of individual local markets are reflected in known conditions and the expression of the desires of local inhabitants themselves. Therefore, the degree of definition permissible in the investigation of small dams varies with the types of goods and services. Thus, while the means for measuring the local markets for some products such as flood control, recreation, and fishing and hunting opportunities, are more readily available than for other goods and services to be produced, the measurement of the needs for these latter products, including water supply, must depend primarily on the initiative of local interests.

16. <u>Flood Control Problems</u>. The defining of local problem areas for flood control required a study of all flood damage information available to the Joint Work Group from Federal, state and local sources, and the delineation of the overall flood problems in the basin according to problem areas. This study, followed by field reconnaissance by members of the Joint Work Group in the reaches with a known high concentration of flood damages, resulted in general locations of local areas which provided a high potential market for flood control measures.

17. Water Supply Problems. Final decisions by local interests as to the sources of water supplies to meet their future needs must be based on economic analyses pertaining to the local problems. The market with respect to local municipalities or rural areas could be defined individually by the desires of local interests or by inclusion in generalized definition of the water supply needs for a larger segment of the basin on projected future demands. Although interest was shown in the water supply potentials of some upstream reservoirs, particularly those in Montgomery and Bucks Counties, Pennsylvania, no specific requests for water supply storage were made by local interests. Therefore, the market for local water supply was included in the generalized demand studies developed in connection with the overall appraisal of water needs for the entire Delaware River basin as defined in Appendix P.

18. Recreation, Fish and Wildlife Problems. An inventory conducted in connection with determining existing supply and demand as they relate to outdoor recreation, including fishing and hunting, and as reported upon in Appendices I, J and W revealed that for the basin as a whole an adequate market exists in all such cases where the several requirements of satisfactory outdoor recreation opportunity can be met by multiple purpose projects. Under such conditions it was concluded that small reservoir projects could serve effectively in partially meeting recreation needs and that in most of these cases the affected market would be local.

19. Rural Water Problems. Specific water needs for rural water uses depend upon the character and land management practices of local areas. The definition of problem areas was determined by the Department of Agriculture in its studies of irrigation and rural water use which are fully described in Appendix G.

SECTION III - PLANNING PROCEDURES

20. GENERAL. The primary planning objective in the intermediate level of development was to locate small dams and reservoirs together with other engineering measures in a usable relationship to the local market discussed elsewhere in this appendix. Initial review of planning goals for the entire basin indicated that this method of approach did not adequately fulfill all requirements for a comprehensive analysis of the overall water resources since it was not only necessary to plan small dams and reservoirs to satisfy local needs but also to provide for some portions of the basinwide needs. This latter condition could be accomplished by increased development at the site beyond that required to fill local needs or by independent development of small reservoirs as auxiliaries to the larger main stream reservoirs. Therefore, to completely satisfy planning goals for comprehensive development of water resources all potential small dam and reservoir sites in the entire basin within certain limitations, were located and appraised. The general planning procedures used in this study consisted of six major steps: (1) map study, (2) selection of sample study sites, (3) general field reconnaissance, (4) detailed office study including review of prior reports and data from state and local agencies, (5) detailed field investigations, and (6) economic evaluations. Detailed chronological descriptions of the above planning steps are given in paragraphs 21 to 26 inclusive.

21. MAP STUDY. Potential dam and reservoir sites were selected from a map study using the following limitations and general assumptions as guides.

a. Potential dam sites would have a drainage area greater than one square mile.

b. Potential dam and reservoir sites should be located on tributary streams with emphasis on those watersheds having a total drainage of less than 250,000 acres.

c. Potential storage capacity in each reservoir would be limited to a minimum of approximately four inches of runoff from the watershed.

d. The area in the reservoir below the top of the flood control pool should be relatively undeveloped. All dam and reservoir sites were initially located on USGS topographic quadrangle maps with a scale of approximately one inch to a mile (1:62,500) and a contour interval of 20 feet. Although many of these maps, because of the date of the publication, do not reflect the latest cultural features, they were used for the initial map study because they afforded complete coverage of the entire basin and allowed a systematic method of recording all sites.

Later, detailed studies were made on USGS and Army Map Service series maps with scales of 1:24,000 or 1:25,000 where they were available. Potential sites were designated on each map by numbers with a prefix representing the abbreviation of the quadrangle name - for example, Gt-4 refers to Site Number 4 located on the Germantown Quadrangle. Watershed boundaries and maximum pool levels for each site were delineated and planimetered on the map. All information for each site, such as location, size of watershed, general size of structure, potential storage capacity, height of structure established from contours, etc., was recorded on Form 785 designed specifically for this study. A sample copy of this is shown on plate 4. Where topographic conditions permitted, reservoir heights were established to provide for storage in excess of four inches of runoff. In a number of cases the maximum potential storage capabilities exceeded the estimated annual yield which could be expected from the area above the structure. Where this occurred the maximum storage for individual structures was based on either the estimated annual yield from the watershed or the limiting physical conditions of the site. With the above assumptions as general guides, a total of 386 potential dam and reservoir sites were located from the map study. A check of current watershed work plans revealed that 26 of the 386 potential sites were previously selected under various watershed studies and had been investigated and reported on in detail in prior reports. These sites were eliminated from further study by the Joint Work Group and reduced the number of sites resulting from the map study to 360.

22. <u>SAMPLE STUDY SITES</u>. Due to the large number of potential small dam and reservoir sites determined from the map study, a sampling method was employed for the purpose of selecting representative sites for more detailed study. Accordingly, 36 sites, or 10 percent of the number of sites under consideration, were selected by random sampling. These sites, shown on plate 5, were found to vary in size of drainage area from 1.0 to 20.0 square miles and to represent the adequately varying physical characteristics at practically all of the 360 sites. Detailed studies including project designs, cost estimates, and benefit and economic evaluations, were made for all 36 sample sites. The field data collected for the 36 sample sites, together with data secured from the actual design of the individual 36 dam sites were used in developing generalized criteria for hydrologic and structural design, cost estimates, and flood control benefits in the evaluation of all potential small dams and reservoirs.

23. GENERAL FIELD RECONNAISSANCE. Although the map study provided general information for preliminary selection of potential dam and reservoir sites in the basin, it was necessary to investigate all sites in the field to check the physical conditions and existing developments in the general vicinity of the site with those shown on the maps. A field reconnaissance was made of each site and pertinent physical data were recorded on Form 785. The information collected consisted of the spillway possibilities in the vicinity of the dam site, topographic features which would affect construction, channel capacities of the stream, soil conditions at the proposed dam site and in relation to borrow areas, and land uses and improvements in the area to be inundated by the reservoir. In addition the general land use downstream from each proposed project was classified and the market potential for water resources products indicated. From the general field reconnaissance it was found that 67 of the 360 sites selected from the map study would be eliminated due to insufficient storage capabilities, poor foundation conditions, excessive urban developments in the reservoir area, and the location of new highways and utility lines in the reservoir area which were not indicated on the maps. This resulted in 293 remaining sites which appeared to have some merit for further investigation and study. These 293 dam and reservoir sites are shown on plate 6.

24. DETAILED OFFICE STUDY. A detailed office study was made of the 293 dam and reservoir sites for the purpose of determining which of the sites would best meet current demands for water resources products. Since previous studies indicated that no specific requests had been made for water supply or recreation needs in local areas the 293 sites were initially appraised only on the basis of flood control needs. These studies consisted of detailed examinations of the best topographic maps available, aerial photographs, and data recorded on Form 785. In addition a review was made of previous reports 3/4/ and all information from state and local agencies. From this study the magnitude and areal extent of the market for flood control was established at each site and damage reach below based on (1) the intensity of land use, (2) the associated human habitation, and (3) the development within the flood plain from each dam site downstream to a point at which the area controlled is five percent or less of the total area. This information was tabulated for each damage reach together with the dam and reservoir projects determined from the map study and general field survey. Where the data for the reaches indicated that there was sufficient justification for flood control measures the individual dam and reservoir sites upstream from these reaches were

3/ 1950 Report Delaware River Basin, Soil Conservation Service.
4/ Flood Survey for Hurricanes "Connie" and "Diane" - Soil Conservation Service, U.S.D.A., Harrisburg, Pa.

identified for further detailed field investigations. A total of 127 sites was identified in this manner and the remaining 166 small dams and reservoirs were given no further consideration in this investigation. Although these latter sites did not indicate sufficient justification for single-purpose flood control projects at the present time, subsequent investigations may show a need for development of a limited number of these sites as single or multiple-purpose projects. All of the 293 small dam and reservoir sites, including the above 166, were considered as auxiliaries to or alternates for major control dams and reservoirs in formulating the plan of development for the entire Delaware River basin.

25. DETAILED FIELD INVESTIGATION. Additional field investigations were made in the local damage reaches below the 127 sites, designated above, for the purpose of securing detailed data on flood damages and physical characteristics of the flood plain in order to evaluate the economic justification of each dam and reservoir project. Included in the 127 small dam and reservoir sites were 13 of the 36 sample study sites designated in paragraph 22. Detailed information collected in the local reaches below the 127 dam and reservoir sites included history of flooding; area subject to flooding; type, number, and valuation of structures within the flood plain; and depths of inundation of the individual structures in relation to a record flood and streambank elevations.

26. ECONOMIC EVALUATIONS. Detailed economic studies of the 127 dam and reservoir sites were based on the design criteria described in SECTION IV, cost estimates described in SECTION V, and average annual flood control benefits described in SECTION VI. A total of 39 of the 127 sites were found from these studies to have annual benefits which approached or exceeded the cost and are considered as having sufficient justification to be included in the general plan of improvement for the Delaware River basin.

SECTION IV - DESIGN CRITERIA

27. GENERAL CONSIDERATIONS. Generalized hydrologic and structural design criteria, defined in subsequent paragraphs, were developed as general guides in the planning of small dam and reservoir projects. These criteria, together with physical data secured by field investigations, are considered adequate for the preliminary designs and cost estimates in this study. For the final design and analysis in connection with the preparation of detailed project reports and work plans, more stringent criteria and detailed data on conditions prevailing at individual sites are required.

HYDROLOGIC DESIGN CRITERIA

28. STORAGE REQUIREMENTS. Criteria for determining storage allocations described in subsequent paragraphs were used for both single and multiple-purpose projects. The three main categories of storage are (1) inactive storage, (2) conservation storage, and (3) flood control storage. The total requirements for storage capacity were determined, as explained below, by an analysis of the runoff characteristics and the nature of the flood problem involved in the watershed under study, together with the need for conservation storage and inactive capacity.

29. Inactive storage. Inactive capacity in the reservoir provides storage primarily for sediment accumulation over the life of the project. The allowance for sediment storage was made on the basis of available data on measured sediment accumulation in existing reservoir projects. Reservoir sedimentation survey records are available from the Subcommittee on Sedimentation, Federal Inter-Agency River Basin Committee. 5/ There are five measurements of sediment in reservoirs within the Delaware River basin and these measured data were supplemented by sediment design data derived from sediment yield studies for drainage areas above all sites proposed for development under current small dam programs in the basin. Similar sediment yield studies were prepared, also, for a limited number of sites selected for detailed investigation by the Joint Work Group. Relationships of sediment yield per unit of drainage area shown on plate 7 were developed to provide an estimate of the average storage reserve necessary for sediment accumulation. Plate 8 shows the general areas of sediment similarity in the basin for which the curves shown on plate 7 are applicable. These general areas of similarity are combinations of problem

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5/ Sediment Bulletin No. 6, Summary of Reservoir Sedimentation Surveys for the United States, Subcommittee on Sedimentation, Federal Inter-Agency River Basin Committee, April 1957.

areas used in land treatment programs. 6/ The combinations of various problem areas were based, primarily, on similarities of topography, soil and soil cover. Consideration of the general nature of the stream slopes, sediment particle size and observation of deposits in existing reservoirs indicates that allocation of space for the entrapment of sediment in reservoirs for each area of sediment yield similarity should be based on the following assumptions:

a. Area 1 of sediment yield similarity. Eighty-five percent of the sediment trapped will be deposited within the limits of the inactive pool and the remaining 15 percent will be deposited elsewhere within the overall physical limits of the reservoir.

b. Area 2 of sediment yield similarity. Eighty percent of the sediment trapped will be deposited in the limits of the sediment pool and the remaining 20 percent will be deposited elsewhere within the overall physical limits of the reservoir.

c. Area 3 of sediment yield similarity. Seventy-five percent of the sediment trapped will be deposited within the limits of the inactive pool. The remaining 25 percent will be deposited elsewhere within the overall physical limits of the reservoir.

30. Conservation Storage. Allocated reservoir capacity designated as conservation storage will include provision for low water augmentation, water supply, fishing and hunting, and recreation. This type of storage is provided for uses that involve long-term impoundment of surplus waters and has its greatest potential value when fully occupied. Required conservation storage was fixed by a generalized relationship of ultimate storage and water yield to drainage area. Generalized water availability studies described in Appendix M, for which all available records at rated stream gages in the basin were utilized, show that the ultimate flow can be estimated using a log-log plot of ultimate storage versus drainage area. The term "ultimate flow" is used synonymously with long term average flow since the average flow is the ultimate that can be realized with complete regulation of the stream. The storage requirement associated with a particular ultimate flow is known as ultimate storage. Ultimate storage, like ultimate flow, is related to the size of the drainage basin and may be conveniently computed from storage factors multiplied by the drainage area in square miles. Optimum development of the storage potential at an ungaged site is dependent on flow-storage relationships derived from ultimate flow and storage values,

6/ Problem Areas in Soil Conservation, U.S.D.A., SCS, February 1953.

and a dimensionless flow-storage curve. In the absence of specific streamflow records at a particular site, a dimensionless flow-storage curve for a rated stream gage in the same or nearby basin is used as the general flow-storage characteristic of the area. The dimensionless flow-storage curve indicates yield in percent of ultimate yield and storage in percent of ultimate storage. The method used to compute the optimum storage and yield is described in Appendix M. Factors of ultimate flow and ultimate storage, and percentages of optimum development are given to table 1. A typical example of the application of the above criteria to a 15 square mile site on the Beaver Kill is as follows: ultimate storage and flow are taken from table 1 and converted by drainage area, 15 square miles, to ultimate storage and ultimate yield at the site equal to 34,500 acre-feet and 34.5 cubic feet per second (cfs) respectively. The optimum point or "knee of the curve," from table 1, is 28 percent of ultimate storage and 77 percent of the ultimate yield. The optimum storage is 0.28 x 34,500 = 9,660 acre-feet and the gross optimum yield is 0.77 x 34.5 = 26.5 (cfs).

31. Flood Control Storage. Flood control storage is provided for short term impoundments of surplus flood waters and has its greatest potential value when unoccupied. Flood control storage will be adequate to regulate the reservoir design flood without discharge through the spillway, assuming the inactive and conservation storage filled at the beginning of the design storm and assuming the flood regulating outlet fully operative during the periods of flood impoundment. Estimates of the hydrograph for the reservoir design flood are based on regionalized rainfall and runoff criteria. In order to determine average flood control storage capacity for planning of small upstream reservoir projects a typical dam site with approximately 25 square miles of drainage area was selected near the center of the Delaware River basin. Regionalized precipitation values were determined in accordance with generalized rainfall estimates published by the U. S. Weather Bureau. 7/ Maximum precipitation amounts over the 25 square miles for a 100-year frequency storm are 4.15 inches for 3 hours, 5.28 inches for 6 hours, 6.38 inches for 12 hours, and 7.50 for 24 hours. The runoff associated with these amounts of precipitation varies with the antecedent moisture and soil cover conditions. It was assumed that throughout the typical area the 5-day antecedent rainfall would vary from 0.5 inches to 1.5 inches. The percentage of runoff, based on weighted soil-cover complexes and average antecedent moisture conditions was found to vary from 75 to 85 percent. Using a 6-hour storm period with the above conditions, the 100-year frequency flood runoff would have a volume of about 4.2 inches. This flood routed through the reservoir, assuming the regulating outlet operative, would

7/ U. S. Weather Bureau, Rainfall Intensity - Frequency Regime, Part 3 - The Middle Atlantic Region. Technical Paper No. 29.

require a storage volume slightly less than four inches of runoff from the controlled area without discharge through the spillway. Initial appraisals of the flood control storage capacity of upstream reservoirs were adopted as being equivalent to a volume of at least four inches of runoff from the drainage areas above the dam site.

32. OUTLET CAPACITIES. Outlets considered for planning of upstream reservoirs fall into two general categories. These are (1) a gated outlet for the release of water supply and low flow augmentation and (2) an ungated flood regulating outlet. The first type is required in a single-purpose conservation project for regulating downstream releases or in a multiple-purpose project as a separate water supply regulating outlet. The flood regulating outlet is required in a single-purpose flood control project or in a multiple-purpose project where flood control is one of the project purpose. In the case of a multiple-purpose project the two types may be combined through a chamber or riser pipe into a single common outlet.

33. Conservation Storage Outlets. Outlet capacities for release of conservation storage are normally based on the water demands downstream. For planning purposes of upstream reservoirs these capacities were fixed to assure flexible and full control of the basin yields. The basin yields are described in the preceding paragraphs on conservation storage. Based on the yield-storage relations the design discharge used for conservation storage outlets is generally 2 (cfs)/sq. mi.

34. Flood Regulating Outlets. In reservoirs containing storage allocation for flood control, the design capacities for flood regulating outlets were selected after careful consideration of the following factors:

a. Downstream Channel Capacity. Discharge capacities at key points below individual dam sites at which appreciable flood damage begins were estimated from field reconnaissance for a large number of proposed reservoir projects. These discharge capacities were used to develop a generalized value of 30 (cfs)/sq. mi. for flood regulating outlet capacities in planning of upstream reservoirs.

b. Time Required to Evacuate the Flood Storage. The time required for evacuation of flood control storage in various reservoirs was computed using 30 (cfs)/sq. mi. as the capacity of flood regulating outlets. Assuming an average value for base inflow of 2 (cfs)/sq. mi. the times required to evacuate flood control storages were found to vary from 5 to 10 days. Additional studies

were made to determine the effect of a spillway design flood entering the reservoir with only 3 to 5 days drawdown from full pool. These studies showed that maximum depth of flow through the spillway was increased between 0.5 and 1.0 foot and the maximum velocity was increased less than 0.5 ft./sec. over normal spillway design conditions as described in paragraph 39.

c. Combined Use of the Uncontrolled Outlet and the Reservoir Storage. In order to effectively control an adequate range of flood flows in the vicinity of the site several record floods were routed through various reservoir storages assuming the uncontrolled outlet operating. These routings were used to determine the best outlet sizes, for use with a limited range of reservoir storages, to effectively reduce flood heights at key points downstream to approximately zero damage stages.

d. Diversion Capacity Required During Construction. Since most of the projects in this study are small (drainage area less than 10 square miles) and require a construction period of less than a year, the diversion capacities required during construction are not an important factor in the determination of outlet capacities. For general planning purposes, the flood regulating outlet selected after consideration of the aforementioned factors was assumed to provide adequately for the required diversion during construction.

35. SPILLWAY CAPACITIES. Criteria for determination of the spillway design storm and resultant flood used in computation for spillway design capacities are given in the following paragraphs.

36. Spillway Design Storm. General storm phenomena and probable maximum precipitation for the spillway design storm adopted by the Joint Work Group are in accordance with estimates of maximum precipitation by the U. S. Weather Bureau. 8/ The estimates of probable maximum precipitation from this source represent the critical depth-duration-area rainfall relations for a particular area during various seasons of the year that would result if conditions during an actual storm in the region were increased to represent the most critical meteorological conditions that are considered probable of occurrence.

37. Spillway Design Flood. The term "spillway design flood" (SDF) applies to that hydrograph finally selected as a basis for estimating spillway discharge capacities required in conjunction

8/ U. S. Weather Bureau. Seasonal Variation of the Probable Maximum Precipitation East of the 105th Meridian for Areas from 10 to 1,000 Square Miles and Durations of 16, 12, 24 and 48 hours. Hydrometeorological Report No. 33.

with various storage capacities (heights of dam) and discharges through other uncontrolled outlet facilities. For major dam structures, the failure of which would create a great catastrophe, the maximum possible flood hydrograph is used for determining spillway capacities. In establishing the spillway design floods used to determine spillway capacities for upstream reservoirs, it was found that, because of the wide range of flood plain development involved, detailed determination of the hydrologic and individual sites would be required as a basis for final design of the structures to be built at the individual sites. Three conditions of flood plain development considered were as follows:

a. Low damage potential with little or no habitation in the flood plain downstream and low average property damages in downstream reaches limited to woods, agricultural lands, and secondary or rural roads.

b. Average damage potential where the proposed sites are some distance above human habitation in the flood plain downstream and average property damages consist of farm buildings, exclusive of homes, public utilities, main highways, and minor railroads.

c. High damage potential with urban or suburban habitation in downstream reaches and high average property damages consist of homes, industrial and commercial buildings, major highways, and main line railroads. Because of the great number of sites under consideration, an average condition of development in the flood plain downstream from each individual site was adopted in lieu of detailed field appraisals of the specific level of development involved at each site. For preliminary design of structures with both high and moderate conditions of flood plain development a nomograph was prepared as shown on plate 9. This nomograph is based on probable maximum precipitation and depth-duration-area data from Hydrometeorological Report No. 33 and loss rates correlated to the hydrologic soil cover complex and antecedent moisture condition used in current watershed programs. Average antecedent moisture conditions and weighted hydrologic soil cover complexes were used to develop numbers indicative of runoff from precipitation. These runoff numbers, developed for the individual problem areas 9/ of the Delaware River basin are shown on plate 10. The rainfall excesses determined from plate 9 were used to compute spillway design hydrographs at each dam site by applying the rainfall excesses to synthetic unit hydrographs determined from generalized procedures described in Appendix M. The resulting spillway design flood hydrograph was used for conditions involving a high degree of development in the protected area and 50 percent of this hydrograph was used as the spillway design flood for conditions with a moderate

level of development in the downstream protected area. The spillway design flood hydrograph in the latter case is approximately the same as a standard project flood hydrograph determined in accordance with directives applicable to major control structures. 10/

38. Spillway Design Capacities for Water Supply Structures. The spillway design inflow hydrograph was routed through the reservoir with the initial pool level at the top of the conservation pool. The spillway was proportioned so that it would pass the spillway design flood reduced by diversions or releases for downstream water supply during the flood period. Since the normal pool elevation will be at the spillway crest in most of the reservoirs considered for water supply purposes, the velocities through the spillway from a spillway design flood will be of such magnitude as to require either a rock or concrete-lined spillway. In some cases, however, retarding storage volume above maximum water supply pool elevation was considered in order to reduce the magnitude of the spillway design discharge and to keep frequent low flows from passing through the spillway. Sodded earth spillways were used under these latter conditions when the maximum spillway velocities did not exceed eight feet per second and frequency of use was generally not greater than once in 25 years. The final determination as to type and size of spillway was governed by physical conditions and construction costs prevailing at the individual sites.

39. Spillway Design Capacities for Flood Control Structures. The spillway design flood hydrograph was routed through the reservoir with the initial pool level at the top of the conservation pool and the flood regulating outlet operative. The crest length of the spillway was fixed by limiting the depth of flow to four feet (determined from maximum pool level above spillway crest) or by limiting maximum velocity through the spillway to eight feet per second. This maximum velocity was adopted as an average for use in planning studies, but it is assumed that in actual design studies the maximum allowable velocity will be determined for conditions prevailing at the individual sites.

40. FREEBOARD. Freeboard was computed in accordance with the following conditions:

a. Two feet minimum above the pool stage determined by routing the spillway design flood through the reservoir with the flood regulating outlets operative and assuming the initial reservoir level to be the maximum stage reached in routing a 50-year frequency flood; or

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9/ Problem Areas in Soil Conservation, U. S. Dept. of Agriculture, Soil Conservation Service.

10/ Civil Works Engineer Bulletin No. 52-8, Standard Project Flood Determinations, Office, Chief of Engineers, Department of Army, 26 March 1952.

b. Three feet minimum above the pool stage determined by routing the spillway design flood through the reservoir with the flood regulating outlets operative and assuming the initial reservoir level to be that of full conservation pool; whichever gives the greater height of dam.

41. HYDROLOGIC DATA FOR SAMPLE RESERVOIR SITES. The hydrologic design criteria described in the preceding paragraphs were used in the detailed studies of the 36 sample reservoir sites. The results of these studies are shown in table R-2.

STRUCTURAL DESIGN CRITERIA

42. Applicability of the Structural Criteria. The intended use of the following generalized criteria dictated that they be generally applicable to all sites encountered in the basin as explained in paragraph 27. In addition to the general criteria some sites may require modified designs in order to make the best use of available local topography and materials. For example these general criteria are based on assumed conditions that will permit the use of sod or rock-lined spillways at sites upstream from reaches with average damage potential as described in paragraph 37. Sites which may be found in detailed final design studies to be located upstream from reaches of high damage potential will require design provisions to assure greater structural safety. These design provisions are greater spillway capacity, higher freeboard, a stilling pool at the downstream end of the outlet pipe, and a rock or concrete-lined spillway with stilling pool. The general design criteria given here do not include added safety features of this nature.

43. Dams for which these general criteria have been established were designed to store the reservoir design flood as described in paragraph 31 which provides for infrequent use of the spillway. If sites or conditions are encountered where storage for such an amount of flood water cannot be provided, the size of the conduit may be increased accordingly or the spillway will be designed to safely permit more frequent operation. Under these conditions the spillway may need to include a concrete crest, lined channel and a lined stilling pool.

44. Data Used in Development of Criteria. These general criteria were based on principles developed through experience in the design and construction of small dams under various watershed programs and established structural requirements of the States in the basin.

A number of references 11/ and a great amount of data were studied and considered during formulation of the structural criteria. The States of Delaware and New York have no formal, published structural requirements for small dams but the State of New York requires approval by the Department of Public Works of designs for dams over 10 feet high.

45. Data Available for Each Site. The great number of sites under consideration precluded field topographic surveys at the individual localities. The topographic data as needed were taken from USGS and AMS maps. Data on approximate channel and valley dimensions were obtained during field inspections of each site. Field observations were made of earth and rock materials at the sites to determine their suitability for use in earth dams built on the side slopes selected in the preliminary designs. Curves showing spillway data as given in the sample shown on plate 11 were prepared for each proposed dam and reservoir. These curves were based on hydrologic criteria and assumed generalized storage conditions as described in paragraphs 35 to 40, inclusive.

46. Typical Structure. Plates 2 and 3 show plan and section drawings for a typical small dam as considered in this report with the method of incorporating the outlet and spillway facilities. Features shown on these plates were adopted as guides for preliminary layout and design of similar structures, each fitted to a particular site.

47. Structural Criteria for Dam. The cross section of the dam was designed as shown on plate 3. The side slopes of 3 on 1 upstream and 2.5 on 1 downstream were adopted as generally acceptable for earth embankments in the basin. Also, it was assumed that the available material would be properly graded to obviate the use of an impervious cutoff. The elevation of the top of the dam was taken as the maximum pool elevation plus freeboard as defined in paragraph 40. Side slopes of the dam generally will be protected by seeding to adapted grasses and, if necessary, by riprapping at vulnerable points.

11/ a. Public Laws 555 and 704, Commonwealth of Pennsylvania, published as Form FWWR-21. (Also the Pennsylvania Fish Commission has some special requirements for small dams.)

b. "Information for Applicants for Construction, Alteration, or Repair of Dam 1947," New Jersey, a pamphlet and 9 mimeographed pages. (Also the New Jersey Fish Commission has some special requirements for small dams.)

c. "Project Formulation and Design Criteria for Small Dams" EM 1110-2-1101 dated 20 December 1957.

d. Engineering Memorandum No. 3, Subject "Limiting Criteria for the Design of Earth Dams and Associated Spillways" Revised 16 July 1956, and "Tentative Technical Release No. 2, 1 October 1956," Soil Conservation Service.

48. Structural Criteria for Outlet. The outlet is designed as a reinforced concrete pipe on a full-length concrete cradle under the dam, or through one abutment at stream bed level, with a riser in the reservoir. The minimum pipe size is 24 inches in diameter. In all cases the pipe will be large enough to carry not less than 30 cubic feet per second per square mile of drainage area with a head sufficient to provide the required storage capacity. Antiseepage collars are provided at not less than two points along the concrete outlet pipe. The downstream end of the pipe was cantilevered eight feet beyond the toe of the dam. The riser in the reservoir was designed with a vortex suppression device and a slide gate, two feet square, near the bottom to permit low level releases and to provide for draining the pool.

49. Spillway. The lined or sod spillway was designed as a broad-crested weir of sufficient width to pass the required spillway discharge in accordance with criteria described in paragraphs 35 to 40, inclusive.

50. RESERVOIR AREA. The reservoir area to be acquired either by purchase or easement was assumed, for purposes of these studies, to be the area inundated at an elevation four feet above the spillway crest. The area up to the elevation of the top of the outlet riser was assumed to be cleared of trees and brush. Roads and utilities in the reservoir area are to be raised or relocated, as necessary.

51. RECREATION FACILITIES. Recreation facilities proposed herein are based on an assumed optimum annual visitation for each of the index projects described in paragraph 64 selected as representative of the general range of topographic and scenic conditions presented by all of the projects considered. For each project offering recreation possibilities the design load was computed by the National Park Service, applying a turnover factor of 1.5 to obtain the total number of visitors expected at any one time on a normal summer Sunday. Land acquisition and facilities for day-use activities including those necessary for interior access, parking, picnicking, swimming, boating, water supply and sanitary facilities are provided.

SECTION V - COST ESTIMATES

52. ESTIMATES OF INITIAL COST. The large number of small dams under consideration required a simplified procedure for making initial rough cost estimates of each project as a basis for identifying those worthy of further consideration. Such a procedure would avoid unnecessary examination of those projects which, upon closer scrutiny would lack economic justification. Also, the estimating procedure had to be applicable for use with only limited reconnaissance type field data available for any specific site. The intended use made it necessary that the procedures take advantage of some generalizations. The derived cost estimates are applicable to dams assuming average condition of development in the downstream protected area where it is practical to impound sufficient flood-control storage to permit the use of sod-lined spillways. Initial or reconnaissance type estimates for dams at sites upstream from reaches with high damage potential, or where a concrete-lined spillway is needed, must be made separately and must be based on designs embodying greater structural safety.

53. Subdivisions of the Estimates. To simplify the procedure, estimates have been divided into the following six cost items:

a. Construction cost of the dam, including the outlet, and the spillway.

b. Fencing and seeding,

c. Contingencies,

d. Engineering and administration,

e. Land and relocations,

f. Recreation facilities.

54. CONSTRUCTION COSTS AND ESTIMATES. Construction costs (item a, paragraph 53) experienced in watershed programs and estimates of construction costs prepared for this Work Group were assembled and analyzed as described in the following paragraphs.

55. Construction Cost of Small Dams Constructed between February 1956 and July 1959 as Features of Watershed Programs. A total of 33 dams shown in table R-3 was constructed by local organizations, such as soil conservation districts, flood control districts and county districts. The designs, contracts and construction were approved by the appropriate Federal agency as provided by existing authorizations. Designs were similar to those shown in plates 2 and 3. The work was

awarded to the lowest competitive bidder at the contract cost shown. These costs are for clearing the dam site areas, and constructing the dams, outlets and spillways. They do not include the costs of land, relocation of roads or utilities, seeding, fencing, contingencies, engineering or administration. The costs (January 1959 price level) per cubic yard of embankment listed in table R-3 are the contract cost at each site divided by the corresponding embankment volume. These figures are greater than the unit bid price for placing embankment, because they include the cost of additional work such as the outlet and spillway. Details of unit prices for these 33 dams are shown in table R-4.

56. Construction Cost Estimates for Small Dams Prepared by Joint Work Group. In addition to the cost data described above, detailed construction cost estimates were prepared by the Joint Work Group for nine of the 36 sample study projects designated in paragraph 22. These dams were selected to cover sizes ranging from 13,750 to 535,440 cubic yards of embankment. All of the nine projects were located upstream from reaches with moderate damage potential and involved the use of sodded earth spillways. A preliminary design was made and quantities were computed for nine work items at each site. Unit prices assigned to each item, based on experience in the general area of the basin, are shown in table R-5.

57. Estimating Experience. Experience in estimating the construction costs of the dams listed in table 4 has indicated that because of the relatively low significance of the costs of some features a reasonably accurate estimate of total cost may be made by calculating the volume of the embankment and multiplying by a single selected price. This price must be based on a consideration of all the various factors likely to affect bid prices, such as: size of the embankment, difficulties anticipated, amount of expected rock excavation, size of outlet, location of the job, time of year at which bids were received, etc.

58. Summary of Construction Cost Data. The experienced construction costs from tables R-3 and R-4 and the estimates from table R-5 have been summarized in table 6 and plotted on plate 12. It will be noted that the relation of cost per cubic yard of embankment vs. yards of embankment shows considerable spread when the experienced costs for small dams located in Virginia and West Virginia are taken into consideration. Also, the bid prices and estimates for small dams in the Pennsylvania portion of the basin show a consistently higher price per cubic yard of embankment than for similar projects in the other states. In using a generalized pricing index based on such data it should be recognized that the costs of projects to be taken under existing authorities must undergo further detailed analyses in the preparation and review of watershed work plans or detailed project reports. In cases where additional authority is

required before the project can be undertaken, reviews of cost estimates must be based on additional field data. From consideration of all of the factors involved it was concluded that an envelope curve based on the bid prices and estimates for small dams in Pennsylvania would provide a reasonable generalized basis, for preparing initial estimates of the constructing costs for small dams under consideration here. This envelope curve shows a cost of $1.67 per cubic yard of embankment for projects with 10,000 yards of embankment, $1.31 for projects with 50,000 cubic yards of embankment, $1.18 for projects with 100,000 cubic yards and $0.93 for projects with 500,000 cubic yards of embankment. The Joint Work Group adopted the envelope curve for purposes of estimating construction costs.

59. Contingencies. In addition to the estimated cost for constructing the dam, agencies active in this type of work customarily add some estimated amount for contingencies. The amount allowed for contingencies must, necessarily, be based on judgment varied according to the stage of planning and design, and the sufficiency and accuracy of the basic data. From consideration of established practice and the relatively simple type of structures involved, the Joint Work Group adopted 20 percent of the construction cost as the amount to be used for contingencies in making preliminary estimates.

60. Engineering and Administration. In addition to the estimated construction cost there are costs for engineering and administration. The engineering work consists of surveys, foundation investigations, materials investigations, preparation of designs, and inspection of construction; and administration includes office overhead, publication of specifications, advertising for bids, receiving and analyzing bids, awarding the contract, maintenance of fiscal records, processing estimates for payments to the contractor, etc. Past experience is the best available guide for an estimate of these costs. It is customary to divide this charge into two parts - one for work charged directly to the project and a small charge, for maintenance of an office or offices not directly responsible for the planning, design or construction. The Joint Work Group adopted the following amounts for these items:

Type of Work	Percent
Surveys, foundation and site investigation design, supervision and inspection, contract administration	20
Maintenance of offices not directly responsible for the work	5
	25

The Work Group adopted 25 percent of the construction cost as the amount to be added for the cost of engineering and administration.

61. Seeding and Fencing. The above described estimate of construction cost includes all work at the dam site, except seeding and fencing. These items are customarily performed by separate contract, because it has been found that better prices are obtained by awarding separate contracts at a favorable time of the year. The average cost for seeding and fencing for 10 projects in West Virginia under watershed programs was:

	Per Site
Seeding; avg. 8 ac./site at an average cost of $250/ac. =	$2,000
Fencing; avg. 150 rods/site at an average cost of $4/rod =	600
Seeding and Fencing, Average	$2,600

Based on this average figure and an additional 15 percent for higher prices found in Pennsylvania as compared to prices in West Virginia the Work Group adopted $3,000 per site as the estimated cost of fencing and seeding.

62. Land and Relocations. This item is also known as "reservoir costs" and "land easements and right-of-way." It includes the cost of land for reservoir area, cost of right-of-way and construction for relocation of roads and utilities; and cost of clearing, exclusive of the area under the dam and spillway. Estimates of reservoir costs adopted by the Joint Work Group were based on actual experience and estimates. The prices per acre estimated by real estate appraisers for the actual purchase or acquiring of flood easements on wooded land in the various subbasins of the Delaware River are as follows:

Subbasin	Wooded Land (per acre)
West Branch	$20.00
East Branch	20.00
Hancock to Port Jervis	120.00
Port Jervis to Belvidere	220.00
Lehigh	30.00
Belvidere to Trenton	50.00
Trenton to Philadelphia	100.00
Schuylkill	50.00
Philadelphia to Bay	100.00

Based on the average costs in the above tabulation the Work Group adopted $150 per acre as the estimated cost of securing land either by direct purchase or easement including clearing.

63. Road and utility relocations generally have been avoided on projects included in the watershed programs, by selecting sites where such changes are not required. Observations made during the field reconnaissance in connection with this study also indicated that generally sites could be found that would not require any appreciable expenditure for relocations. Therefore, no costs were included for relocations in estimating general construction costs of small dam and reservoir projects under consideration by the Joint Work Group, except in the one project Pc-9 described in paragraph 77.

64. Estimate of Cost of Recreation Facilities. Three typical projects were selected with a view to providing one sample each of three general conditions of topography and engineering design. All pertinent dam and reservoir data on the three projects were assembled and these, together with a topographic map of the sites, were submitted to the National Park Service for study and appraisal of the recreation potential and allied costs. For each project, the National Park Service developed cost estimates for facilities consistent with an estimated annual attendance load at optimum use level. The physical features of the representative site locations were appraised, including depth and size of reservoir, topography and scenic characteristics. Design assumptions including optimum annual visitation and design visitation loads, furnished by the National Park Service, were developed as a basis for determining the kind and extent of facilities to be built at each site as well as the amount of land required for recreational use. Design assumptions, facilities to be constructed, land to be purchased and estimates of cost are given to table R-7 for two typical sites. Site No. 1 of the three sites was found to be unsuitable for recreational development and is not shown in table R-7. Further study of other sites being considered will undoubtedly disclose that on account of limited size, location, physical features and other factors, many of them would have little recreation potential and thus development for recreation would not be justified.

65. ESTIMATE OF OPERATION AND MAINTENANCE COSTS. Experience on maintenance of dams of this type has been that the following work is required:

a. Mowing the dam embankment and spillway twice a year.

b. Adding fertilizer and lime to the sodded area every two years.

c. Inspecting and painting the trashrack every year.

An estimated operation and maintenance cost of $300 per year was used by the Work Group in evaluating the projects reported on herein.

66. <u>SUMMARY OF ESTIMATING COSTS</u>. The first cost of the project as presented in this appendix is based on the sum of the following six items of estimated costs.

a. Cost of dam, outlet, and spillway - described in paragraph 58.

b. Fencing and seeding - $3,000 per site.

c. Contingencies - 20% of a. and b. above.

d. Engineering and administration - 25% of a, b, and c above.

e. Land and relocations - described in paragraph 62.

f. Recreation facilities including land - described in paragraph 64.

After determination of the estimated first cost, the estimated annual cost was computed as the sum of the following items:

g. 2.50 percent of estimated first cost for interest.

h. 1.026 percent of estimated first cost to provide for amortization in 50 years, and

i. $300 for operation and maintenance.

SECTION VI - METHODS FOR EVALUATING HYDROLOGIC AND ECONOMIC EFFECTS OF RESERVOIRS

67. GENERAL METHODOLOGY. A high percentage of the upstream dam and reservoir projects under consideration fall within the cost and capacity limits of projects that can be accomplished without further approval of various committees of the Congress under existing authorities discussed in paragraphs 2 to 7, inclusive. Watershed work plans or detailed project reports presenting detailed benefit-cost appraisals must be prepared and approved prior to construction of projects under the existing programs. Accordingly, to avoid duplication of effort such appraisals were not undertaken here. However, in order to firm up the total list of small reservoir projects that appear economically feasible at this time, generalized procedures were established for making an initial appraisal of the economic worth of the small reservoir projects under consideration. As indicated in paragraph 15, the means for measuring the local market for flood control derived from reservoir projects usually are available. Furthermore, data required for the evaluation of the hydrologic and economic effects of flood control features of small dams and reservoirs can be developed from available physical data secured by field surveys. Because of their practical aspects the appraisals of flood control effects were used as indices of preliminary economic feasibility of multipurpose development of small reservoir projects. It is recognized that the use of this single purpose index may occasionally result in the oversight of worthwhile single purpose projects for, say, water supply or recreation and, also, in rare cases may result in the omission of worthwhile multipurpose project that, because of unique conditions attending them, do not attain high flood control indices. Worthwhile projects omitted due to such occasional oversights will be readily added to the watershed programs when the need for them creates local support for their development. The flood control appraisal, therefore, afforded acceptable and practical indices to the economically feasible projects in the intermediate levels of development.

68. PROCEDURES FOR ASSIGNING MONETARY VALUES TO RESERVOIR EFFECTS. In order that the upstream reservoir program fit in with the comprehensive approach described in Appendix Q, it was necessary to assign values to all associated goods and services for which there was a need and demand that could be so satisfied. Furthermore, while the use of the flood control index, described in paragraph 67, indicates the need for monetary appraisals only in the case of flood control benefits, the complete appraisal of projects for which additional approval is required makes it mandatory that procedures be established for assigning monetary benefits to all project purposes. The starting point for assigning such benefits to water resources products resulting from small reservoir projects is the market price system.

Although some of the project benefits may be difficult to evaluate completely, an adjusted or estimated market value in monetary terms was given to each project purpose, insofar as practical, in order that all project benefits could be summed up in the same terms.

69. Flood Control Benefits. The classification of flood damages and determination of damage-frequency-benefit evaluations by normal procedures are described in detail in Appendices M and D and are briefly summarized in subparagraph 69a. It was not practicable to utilize these normal procedures for all small dam and reservoir projects under consideration, since the demands placed on available funds and manpower for such detailed investigations are not warranted from the standpoint of survey scope reporting. Accordingly, generalized procedures for determining the hydrologic and economic effects of small reservoirs were developed from detailed studies of the 36 sample sites, referred to in paragraph 22, and 37 sites previously investigated under separate watershed programs in the basin. The results of these studies based on annual flood damages and benefits for these 73 sites determined by normal procedures, cited above, are given in subparagraph 69b. These studies indicated that the extent of hydrologic effect due to the small dams and reservoirs was limited, for all practical purposes, to the local reach from the dam site to a point downstream at which the area controlled by the dam is five percent, or more, of the total area above such downstream point. This places the downstream limit of the local reach at the mouth of the tributary stream on which the structure is located, or at a point usually 15 to 20 miles downstream. The reservoir effects below this point are diminished to such magnitude that an accurate appraisal of them is impractical. The hydrologic and economic effects of small dams and reservoirs in damage reaches farther downstream below the local reaches were considered in major control studies and are treated in Appendix Q.

a. Normal Procedures for Determining Annual Flood Damages and Benefits. The normal procedures for determining damage-frequency-benefit evaluations of flood control reservoirs are as follows:

(1) Reservoir inflow flood hydrographs were routed through reservoir storage using the basic routing equation; outflow (o) equals inflow (I) minus change in reservoir storage (S).

(2) The outflow hydrographs from the reservoirs were then routed through downstream channel storage, using the Wilson routing method 12/, to the established reference gage in the local damage reach.

12/ Wilson, W. T., "Graphical Flood Routing Method," Trans. American Geophysical Union, pp. 893-897, 1941.

(3) The routed outflow hydrographs at the reference gage were subtracted from the natural flood hydrograph at the gage to obtain the reduction in flow due to the reservoir.

(4) Several floods were routed in this manner and the reservoir effect for each flood was plotted as a reduced peak flow below the natural frequency curve. A modified frequency curve was drawn through these points using the shape of the natural curve as a guide.

(5) Stage-damage curves were established by relating the detailed flood damage data collected in each reach to depths of flooding or gage heights at the reference gage.

(6) Correlation of the modified discharge-frequency curve with the stage-damage curve and stage-discharge curve resulted in natural and modified damage-frequency relationships from which annual damages and benefits were measured.

b. Generalized Procedures for Determining Annual Flood Damages and Benefits. A generalized procedure for determining annual damages and benefits, based on the results of detailed studies of 73 sites, is outlined as follows:

(1) Generalized average percentage factors were first developed from the detailed flood damage data collected for the 73 sites described above. The procedure for deriving these factors is given for typical residential properties. The residences were grouped into three categories on the basis of magnitude of physical damage. The three categories being low damage for residences subject to lawn damage only, medium damage for residences with basement damage, and high damage for residences with damages above the first floor level. The annual percent damage factor was computed for each individual residence by dividing the average annual physical damage by the actual valuation. This annual rate of physical damage, expressed in percent of the residential value, was found to average 2.0 percent for first floor flooding, 1.0 percent for basement flooding and 0.5 percent for lawn flooding. Annual physical damage factors in terms of percent of property valuation were developed similarly for other classes of damages.

(2) Data on business losses and costs of emergency measures were analyzed for the 73 sites and generalized percentages of these losses to physical damages were developed. Based on these analyses, the total tangible damages to residential property and agricultural land and improvements were estimated as 115 percent of the physical damages for these properties, and the total tangible damages to commercial establishments, retail stores, roads and bridges were estimated as 125 percent of the physical damages. Average annual physical damages for the sparsely developed areas in the remainder of

the reach together with farm roads, secondary public roads and bridges were estimated as being equivalent to 20 percent of the physical damages in the intensely developed section of the reach.

(3) Average annual benefits for the reaches below the 73 study sites were converted in each case to a percentage of the total average annual damages for each reach. The percentage of drainage area controlled by each of the 73 study sites was computed by dividing the drainage area above the individual dam site by the total drainage area above the reference gage in the downstream reach. The percentage of the drainage area controlled was plotted against the percentage of reduction of annual damages for each of the 73 study sites, and the curve shown on plate 13 was developed.

70. Water Supply Benefits. As referred to in paragraph 17 there are, at present, no specific requests by local interests for water supply storage in upstream reservoir projects. The principal objective in assigning monetary benefits to water yields is to compare the potential benefits for water supply of upstream reservoirs with major control projects as possible alternates or additions to the major projects for overall basin water supply needs. The general rule followed in project formulation in this report is that a water supply project or water supply separable segment of a multipurpose project should be more economical than any other actual or potential available means, public or private, of accomplishing that specific purpose. Because of the large number of small reservoirs which had to be investigated as possible alternates for large projects, a generalized procedure was developed for determining water supply benefits based on the cost of providing water supply per unit of reservoir yield. All available information on existing and proposed water supply projects was assembled. Total dam and reservoir costs, including operation and maintenance, reduced to an annual basis, were plotted against net yield in (cfs) as shown in plate 14. Optimum yields and storages for each upstream reservoir were determined in accordance with the criteria described in paragraph 30.

71. Recreation Benefits. A generalized method was developed for evaluating recreation benefits in connection with upstream reservoir projects. Benefits for these projects would be limited by the cost of obtaining the same facilities and opportunities by the least expensive alternate means, such as cost for developing, operating and maintaining parks with like facilities and opportunities. This alternate cost data would be determined and applied on each site or series of sites when required.

72. Fish and Wildlife Benefits. It is proposed that at such time as any of these projects are to be initiated for construction, fish and wildlife studies will be conducted to determine the effects such projects would have on the fish and wildlife resources. These

studies would consist of field investigations to determine the quality of the existing fish and wildlife habitat resources, utilization by hunters and fisherman, and the potential development of these areas as contained in plans of State and Federal fish and wildlife agencies. Following this, studies would be conducted on the hydrological, design and operational characteristics of the project to determine the effects on the existing resources, and to evaluate the incidental effects of the project on satisfying the needs of the people for the fish and hunting that would be produced by the project. These latter benefits would be estimated in accordance with procedures acceptable at the time such projects are initiated. In any case it is contemplated that these methods would include estimates of utilization and the monetary equivalent thereof. 13/ The difference between past and present project benefits would indicate the net project benefits and costs. Where needed and economically feasible, additional features for enhancement of the fish and wildlife resource would be provided. The extent to which enhancement features would be provided would be in accordance with the desires of appropriate interests responsible therefor at the time of initiation of the project. Investment in enhancement features would be limited by the least costly single purpose alternate project producing the same benefits.

73. Irrigation Benefits. Assigning a benefit to water for irrigation involves collecting, tabulating and analyzing data relating kinds of crops irrigated, the response of crop yields to irrigation, prices received and costs. Data collected from New York, New Jersey and Delaware agricultural experiment stations were used to obtain an average increase in crop yield due to irrigation. This amounted to 34 percent for the period of 1938-1956. Based on crop prices for the period 1949-1955 and the average increase in yields for the 18-year record, the net gain due to irrigation was approximately $65 per acre annually. Returns were computed on the basis of water being available at the farm at zero head. In making projections for the future, long-term projected prices were used. By multiplying the yield increases by the projected long-term prices, a gross benefit increase per acre of major crops irrigated was about $89.00. This figure was then adjusted to reflect the cost of irrigating and the weighted cost of increased production costs. The long-term net return due to irrigation was computed to be about $42 per acre annually. On this basis the long-term projected net gain per acre-inch of irrigation water was computed to be about $5.26. The net value per acre-foot of water delivered to the farm would be $63. Additional storage must be provided to compensate for unavoidable storage and delivery losses.

13/ Methods for making such appraisals are presently under study by the Subcommittee on Evaluation Standards of the Inter-Agency Committee on Water Resources.

This may require the storage of 1-1/2 to 2 acre-feet of water for each acre foot delivered to the farm. The cost of delivering water to the farm plus this allowance for additional storage would be deducted from the $63 to determine the maximum justified expenditure per acre-foot of storage. Thus the irrigation benefits would be $30 to $40 per acre foot of water at the reservoir for irrigated land producing high value crops.

74. Low Flow Augmentation. In addition to reducing flood flows, small dams and reservoirs may also be used to augment low flows through the release of conservation storage. The degree of augmentation that can be achieved will depend on (1) the available natural yields of the subbasin in which the project is located, (2) the size of the drainage area above the individual dam and reservoir, and (3) the actual quantity of storage allocated to conservation requirements. Although assignment of values to low flow augmentation has not been undertaken, it is recognized for the purposes of this analysis that increased low flows would be provided from multiple purpose projects by normal releases for specific purposes, such as, water supply, fish and wildlife requirements, and irrigation. The magnitude of increased flows will depend on the required demands for the various uses. Single purpose flood control structures are designed with inactive storage capacity which is an allowance for sediment accumulation over the life of the project. This inactive storage, which is generally less than five percent of total storage, is normally not considered as being available for dependable low flow augmentation by direct release. However, through increased ground water recharge and minor percolation under the dam, normal low flows are generally sustained or increased immediately downstream from the site. In cases where it appears that the geology of the site does not permit a significant increase in low flows by the ground water effects of inactive storage, or where other considerations dictate, low flows will be made possible by providing a controlled outlet near the bottom of the inactive storage pool.

SECTION VII - ECONOMIC APPRAISAL AND RESERVOIR DEVELOPMENT POTENTIAL

75. IDENTITY OF FLOOD PROBLEM AREAS OF PROBABLE ECONOMIC FEASIBILITY. A study was made, as explained in paragraph 24, to locate areas of limited extent potentially susceptible to moderate to high intensity flood damage. This was supplemented by a field reconnaissance of damage areas, storm reports and previous damage studies. The local centers and reaches with moderate to high flood damage potential identified from this study were tabulated and summarized by subbasins as shown in table R-8. General descriptions of the floodwater problems in each subbasin are given in the following paragraphs:

a. Subbasins 1 and 2 - West Branch and East Branch. The topography of these subbasins on the western slope of the Catskills is mountainous. The streams are steep, with deep narrow valleys. Due to the narrow valleys, the extent of agricultural land in the flood plain is relatively small and represents scant justification for flood protection. Homes and roads built along many of the small streams have experienced floodwater damage. Flooding of East Brook and West Brook in Subbasin 1 has caused substantial residential, agricultural and road damage. No local damage centers were found in Subbasin 2 with sufficient annual damages to justify impounding structures.

b. Subbasin 3 - Hancock-Port Jervis. The topography of this subbasin is characterized by the Catskill and Pocono Mountains. Streams have steep gradients and narrow flood plains. Recreation is important in the area, with many summer homes and resorts built along the streams. Floodwater control measures are indicated for some localities and appear to have justification potential on the North Branch of Callicoon Creek. Watershed plans for development of small reservoirs have been completed for Lackawaxen River tributaries and Wallenpaupack Creek.

c. Subbasin 4 - Port Jervis-Belvidere. The topography ranges from low mountains to hills with moderately steep slopes. Recreation is important in this subbasin and many homes, resorts and roads along the small streams have suffered severe damage. The need for protection of agricultural land is significant in the southern part of the subbasin. The Pequest River project has been completed and provides protection to agricultural land by means of channel improvement. Streams on which protection is needed are Brodhead Creek and Pocono Creek and some of their tributaries. A watershed plan for control of the flooding on Paulins Kill by small reservoirs has been completed.

d. Subbasin 5 - Lehigh. This subbasin is located in the Appalachian Valley and Ridge Section and in the low mountainous area of limestone soils. There exists a need for protection for agricultural

land and urban areas along the streams tributary to Lehigh River. However, the intensity of development and use of the flood plains along these streams does not represent a high potential for justification of flood control measures. The following streams have local damages of sufficient magnitude for probable justification of improvements: East Branch of Monocacy Creek, Aquashicola Creek and Mauch Chunk Creek.

e. Subbasin 6 - Belvidere-Trenton. This area is in the Piedmont Section, with rolling topography of low hills and streams having moderate gradients. The need for protection in this subbasin is dispersed, and the present justifications for structural measures are limited to Bushkill and Little Martins Creeks.

f. Subbasin 7 - Trenton-Philadelphia. This subbasin lies mostly in the Coastal Plain Section. Topography is slightly rolling to flat, having low stream gradients. Sites for retarding structure are limited. This area has a rapidly expanding population. Many homes, businesses and industry have suffered floodwater damage along some of the streams. Many potential flood control storage areas are occupied by extensive improvements which will limit the use of impounding structures. Little Neshaminy Creek and a tributary of Tacony Creek are considered to have local floodwater damages of sufficient magnitude to justify structural measures.

g. Subbasin 8 - Schuylkill River. Schuylkill River rises in the Appalachian Valley and Ridge Section and flows through the Ridge and Valley area of Berks County, Pennsylvania, the gently undulating to rolling topography of the Triassic Basin of sandstone and shale, and the Piedmont Plateau area. Tributaries of the Schuylkill River range from steep or moderate gradient with narrow valleys to moderate gradient with medium width valleys. Floodwater damage to local urban areas, roads and agriculture have occurred frequently on a number of the streams. Floodwater impounding structures are included in a watershed plan for the Little Schuylkill River and its tributaries. Additional floodwater impounding structures are needed on Stony Creek and Wissahickon Creek.

h. Subbasin 9 - Philadelphia-Bay. This subbasin is mostly in the Coastal Plain physiographic region, with a small part in the Piedmont Plateau problem area. Development and use of the flood plain for homes, industry and business are increasing and the present need for local flood protection, which is already significant, can be expected to increase. A plan for the Brandywine watershed has been extensively studied by local watershed organizations for development under existing authorizations.

76. ECONOMIC APPRAISAL. As previously stated in paragraph 67, the appraisals of flood control effects were used as indices of the economic feasibility of multipurpose development of small dam and reservoir projects. With this approach the 127 small projects, for which flood control needs appeared to exist after initial screening of the 386 sites, were appraised initially, in groups above designated damage reaches. These appraisals utilized generalized procedures discussed in subparagraph 69b. A step by step example of this procedure for a typical damage reach is shown in table R-9. This investigation by group analysis indicated that 53 projects were economically justified. Additional studies of these 53 projects were made on an individual basis and showed that for 11 of these projects the estimated annual project costs exceeded the annual flood control benefits. Included in the 53 projects were 32 small dams and reservoirs located in the Brodhead Creek and Pocono Creek basins. Because of the complexity of these two watersheds and the large number of sites involved, detailed values of flood damages and benefits for the 32 projects were computed using normal procedures described in subparagraph 69a.

77. Eliminating the 11 small dams and reservoirs, cited above, from further consideration as justified projects resulted in a total of 42 which range in capacity from 227 to 5,540 acre-feet, and in estimated construction costs from $70,140 to $1,086,900. An analysis of capacities and estimated costs for each individual project revealed that all except six could be constructed under existing small dam programs without further authorization from Congress. Detailed studies of design, costs, and benefits of these six projects were made in accordance with the requirements for survey scope investigations. Results of these studies showed three of the projects lacked economic feasibility since detailed estimates of annual costs exceeded the annual benefits. General descriptions and detailed cost estimates of the remaining three projects are discussed in the following subparagraphs.

PARKSIDE (Pc 8) PROJECT

The Parkside (Pc 8) dam site is located on Cranberry Creek, one mile southeast of Parkside, Pennsylvania and 0.5 miles upstream from the confluence with Paradise Creek. The creek occupies a narrow wooded valley, with the Delaware, Lackawanna and Western Railroad running parallel to it high on the left (east) side.

The site is covered with glacial drift containing numerous boulders. A low cliff of siltstone and shale exposed on the right bank about 700 feet downstream from the dam site, is the nearest exposure of bedrock. The spillway on the left abutment would be cut into glacial drift material.

The proposed dam would be a rolled earth fill with a 23-foot wide top at elevation 835, 80 feet above the stream bed. Streamflows, other than floods, would pass through an outlet pipe 3-1/2 feet in diameter, having a riser up to elevation 768. A slide gate, two feet square, near stream bed elevation will permit release of water from the bottom of the reservoir. The concrete-lined spillway around the left end of the dam would be 70 feet wide with an "overflow" type crest at elevation 822 and would be approximately 650 feet long from crest to the end of the lining where it empties into the creek.

The reservoir up to the elevation of the outlet riser would store 52 acre-feet of water and would form a pool of seven acres surface area. Between the top of the riser and the spillway crest, the reservoir would store 2,218 acre-feet. At the spillway crest elevation the reservoir would extend about one mile upstream and would cover 107 acres. No relocations would be made necessary by the development of this reservoir.

The plan of this project is shown on plate 15 and details of the cost estimate are given in table R-10.

SWIFTWATER (Pc 9) PROJECT

The Swiftwater (Pc9) dam site is located on Swiftwater Creek 2.5 miles east of Swiftwater, Pennsylvania and 0.8 miles upstream from the confluence with Paradise Creek. The valley at the dam site is flat-bottomed and about 400 feet wide with idle fields and brush in the flood plain. The hills on either side are partly wooded, rising over 300 feet above the valley floor. A paved secondary highway runs parallel to the valley along the left (north) side about 25 feet above the creek.

At the dam site there is an outcrop of shale on the left abutment between the road and the creek; but on the right abutment and in the stream bed bedrock is covered by glacial fill.

The proposed dam would be of rolled earth fill with a 25-foot wide top at elevation 958, 88 feet above the stream bed. Streamflows, other than floods, would pass through a 4-foot diameter outlet pipe with a riser up to elevation 888. A slide gate two feet square, near stream bed elevation will permit release of water from the bottom of the reservoir. The unlined spillway 70-feet wide around the right end of the dam would be approximately 850 feet long from the flat crest at elevation 942 to its discharge into a small existing reservoir downstream from the dam site. It was estimated that excavation for the spillway channel would be in rock.

The reservoir up to the elevation of the outlet riser would store 71 acre-feet of water and would form a pool of nine acres surface area. Between the top of the riser and the spillway crest, the reservoir would store 3,279 acre-feet. At the spillway crest elevation the reservoir would extend about one mile upstream and would cover 107 acres. This reservoir would make it necessary to relocate about 2,000 feet of road which runs parallel to the reservoir site. An additional 4,000 feet of the road would be subject to inundation only on those rare occasions when the reservoir might be filled; but the infrequency of such floods and the existence of other roads to serve the same areas would make it unnecessary to relocate all of the road which lay in the reservoir area.

The plan of this project is shown on plate 16 and details of the cost estimate are given in table R-11.

JIM THORPE (Hz6) PROJECT

The Jim Thorpe (Hz6) dam site is located on Mauch Chunk Creek 2.9 miles upstream from its confluence with the Lehigh River at Jim Thorpe (formerly Mauch Chunk), Pa. The creek lies in a narrow wooded valley between Pisgah Mountain on the north and Mauch Chunk Ridge on the south. A paved secondary highway runs along the left (north) side of the valley about 100 feet above the stream at the dam site. The ground is littered with glacial boulders, especially on the south side of the valley.

The proposed dam would be a rolled earth fill with an 18-foot wide top at elevation 988, 53 feet above the stream bed. Streamflows, other than floods, would pass through a 3-1/2-foot diameter outlet pipe with a riser up to elevation 953. A slide gate, two feet square, near stream bed elevation will permit release of water from the bottom of the reservoir. A concrete lined spillway around the left end of the dam would be 50 feet wide with a flat crest at elevation 976 and would be approximately 650 feet long from crest to the end of the lining. From there, an earth channel about 500 feet long would carry flood flows back to the creek bed.

The reservoir up to the elevation of the outlet riser would store 80 acre-feet of water and would form a pool of 14 acres surface area. Between the top of the riser and the spillway crest, the reservoir would store 1,520 acre-feet. At the spillway crest elevation the reservoir would extend about 1.5 miles upstream, and would cover 130 acres. No relocations would be made necessary by this reservoir.

The plan of this project is shown on plate 17 and details of the cost estimate are given in table R-12.

78. Following the procedures described in paragraph 69 for appraising flood control benefits and the methods for determining costs given in Section V, development of 39 small dams and reservoirs including the three projects listed above, was found to be sufficiently close to economical justification to warrant further study. An indication of the effects of these projects is given in table R-13 which shows the peak flows for selected frequencies with and without reservoirs for typical control points in some of the downstream reaches. Storage capacities and estimated costs of the 39 small dams and reservoirs are shown in table R-14. Summaries of estimated total cost, and of annual costs and benefits for the 39 projects are given in tables R-15 and R-16, respectively.

SECTION VIII - ROLE OF UPSTREAM RESERVOIRS IN THE INTEGRATED PLAN FOR COMPREHENSIVE DEVELOPMENT OF WATER RESOURCES

79. <u>SUMMARY</u>. The integration of small dams and reservoirs into the overall plan of development for the Delaware basin as features of intermediate development levels was made on the basis of two considerations: (1) satisfying the needs of water resources products in local areas, and (2) augmenting, or possibly substituting for, the major reservoir control projects. The study of local needs with regard to flood control benefits, resulting in the final selection of 39 sites shown on plate 18, is covered in this appendix. On the basis of available information it appears that 36 of these 39 projects might be eligible for accomplishment under available existing, authorities. Consequently it appears that specific authorization for those projects would not be required. However, before decision as to adoption or approval of these projects for accomplishment under existing authorities each location must be studied in further detail. Such detailed consideration can be undertaken under the procedures applicable for the pertinent existing authority.

80. Having determined the economic justification of the three small dam and reservoir projects identified as Parkside, Swiftwater, and Jim Thorpe, on the basis of their flood control benefits, they were then appraised with regard to their multiple-purpose potentials. The local, municipal and rural water needs which could be served by the Parkside and Swiftwater projects are in the lower reaches of the Brodhead-Pocono basin in the vicinity of Stroudsburg and East Stroudsburg. The water needs of these localities have already been accounted for in the overall basin demands, described in Appendix P. As a result, any additional storage in the Parkside and Swiftwater projects for water supply in this area was not considered since the cost of supplying the water supply demand would be greater than the proposed means of securing this required flow from Tocks Island Reservoir. In the case of the Jim Thorpe reservoir, the local water supply needs that could be supplied by additional storage in this project for the town of Jim Thorpe, Pennsylvania and adjacent area along Lehigh River are already being provided for at a lesser cost by storage allocations in the proposed modification of the Bear Creek project.

81. In addition to the three sample sites in paragraph 64, Jim Thorpe, Swiftwater and Parkside sites were examined to determine the recreation potential that would be realized within two possibilities of recreation development. One possibility considered the provision of access and recreation facilities for the single-purpose flood control project at each site. Here the inactive pool would provide the recreation water. The other possibility considered modification of the flood control project to include recreation as a project purpose. In this consideration the cost of raising the height of

the dam to provide a recreation pool of adequate size was estimated as a recreation cost. These costs are summarized in table R-17, together with the real estate and facilities required.

82. These preliminary studies suggest that economic feasibility of modification of the three sites is sufficiently indicated to require that non-Federal desire and willingness to participate be determined at such time as these projects are initiated. In the event that non-Federal interests would then desire to support the recreation development at these sites, the Federal share of specific recreation costs, exclusive of real estate costs, would not exceed that estimated for the development of the inactive pool of the single-purpose flood control project in each case.

83. A total of 293 potential small reservoir projects was investigated to varying degrees in this study. Of these 39 have been found to have sufficient economic values to warrant their inclusion in the overall plan as worthwhile improvements at the intermediate levels of development. General data for maximum development at each of the remaining 254 sites are given in table R-18. As discussed in Appendix Q, it is recognized that these 254 potential small reservoir projects may prove worthwhile in groups as major control developments, as alternates for major control projects under consideration or as augmentations of major control projects. Such considerations are pertinent to the overall study of the development of the basin's water resources and were integrated into appropriate levels of the overall planning studies as reported on in Appendix Q.

TABLE R-1

FACTORS FOR DETERMINING OPTIMUM CONSERVATION YIELDS AND STORAGES

Tributary Basin	Ultimate Flow cfs/sq. mi.	Ultimate Storage 1000 ac.-ft. per sq.mi.	Knee of Curve % Flow	Knee of Curve % Storage
Beaver Kill	2.30	2.30	77	28
E.Br. Delaware R. above Pepacton Reservoir	1.90	1.70	73	29
W.Br. Delaware R.	1.80	1.58	84	42
Lackawaxen R.	1.50	2.30	73	27
Neversink R.	2.10	2.10	81	28
Brodhead Cr.	1.70	1.80	70	25
Tohickon Cr.	1.50	1.50	68	30
Brandywine Cr. above Chaddsford	1.35	1.50	61	18
Lehigh R.	2.00	3.00	75	30
Schuylkill R. above Berne	2.00	3.80	73	18
Tulpehocken Cr.	1.43	2.40	75	15
Perkiomen Cr.	1.60	1.80	68	30
Flat Brook	1.70	1.70	62	20
Pequest R.	1.50	1.70	63	15
Paulins Kill	1.50	2.30	75	25
Beaver Brook	1.50	2.00	70	22
Musconetcong R.	1.70	2.40	73	19

TABLE R-2
DATA ON 36 SAMPLE STUDY SITES - SMALL RESERVOIRS

Site No.	Drainage Area (D.A.) (sq.mi.)	Stream Length (L) (miles)	Stream Slope (S_{st}) (ft./ft.)	Spillway Design Flood Inflow: Runoff Volume (inches)	Spillway Design Flood Inflow: Peak Q (c.f.s.)	Sediment Storage (ac.-ft.)	Flood Control Storage (ac.-ft.)	Total Storage (ac.-ft.)	Spillway: Spillway Peak Q (c.f.s.)	Spillway: Spillway Width (ft.)	Spillway: Head Above Spillway (ft.)	Spillway: Spillway Crest Elevation (ft. m.s.l.)	Top of Dam Elevation (ft. m.s.l.)	Height of Dam (ft.)	Maximum 1/ Flood Control Storage (ac.-ft.)
An 3	7.2	3.60	.0570	8.9	5,550	55	1,536	1,591	3,240	180	3.7	1,322.9	1,336.6	85.6	1,780
By 4	4.1	3.62	.0216	11.0	3,110	90	875	965	2,250	125	3.8	560.5	567.5	47.3	1,170
By 8	2.45	2.71	.0177	10.4	1,900	61	523	584	1,300	65	3.7	833.0	839.0	39.7	720
By 14	2.0	2.01	.0106	11.1	1,650	53	427	480	510	25	3.4	346.2	352.6	32.6	720
Da 9	6.3	5.56	.0224	8.6	4,020	51	1,344	1,395	1,520	80	3.7	1,540.0	1,546.7	96.7	1,600
Da 11	5.8	4.00	.0306	8.8	4,300	46	1,237	1,283	2,120	115	3.7	1,649.0	1,655.7	119.7	1,408
Da 13	5.3	4.16	.0204	8.8	3,600	43	1,131	1,174	1,530	80	3.7	1,741.0	1,747.7	55.7	1,375
Dp 18	1.9	2.10	.0394	9.5	1,920	21	405	426	690	30	3.8	1,342.0	1,348.8	68.8	510
Dy 3	1.0	2.73	.0079	10.9	625	36	192	228	250	10	3.3	369.7	376.0	36.0	410
Gt 7	1.9	2.35	.0185	11.1	2,060	52	404	456	1,020	65	3.7	243.8	250.5	23.9	650
Gt 8	2.8	3.31	.0053	11.0	1,680	68	597	665	1,150	60	3.7	137.4	144.1	44.1	845
Hs 3	15.2	6.04	.0071	10.0	9,530	258	3,243	3,501	7,400	400	3.7	1,391.6	1,398.3	58.3	3,750
Ht 1	1.6	2.48	.0322	8.8	1,450	18	341	359	740	30	3.8	1,639.5	1,646.3	65.3	420
La 1	20.0	8.50	.0071	10.1	10,940	330	4,267	4,597	7,875	400	4.0	278.0	285.0	45.0	4,930
Ln 2	10.6	5.89	.0038	10.6	5,970	191	2,261	2,452	2,650	125	3.7	490.1	496.8	36.8	3,240
Le 4	4.7	3.29	.0399	9.2	4,100	39	1,003	1,042	2,040	115	3.7	1,027.7	1,034.4	88.4	1,165
Ln 4	6.0	3.92	.0408	9.7	5,400	48	1,280	1,328	2,400	125	4.0	1,326.0	1,333.0	77.0	1,550
Ln 7	7.5	3.41	.0306	9.2	6,300	56	1,600	1,656	2,660	140	3.9	1,634.8	1,641.7	164.7	1,970
Mg 4	6.2	4.95	.0264	9.3	4,650	49	1,320	1,369	2,140	115	3.8	1,759.0	1,765.8	95.8	1,550
Nt 1	2.1	2.21	.0164	11.1	1,800	56	448	504	1,000	50	3.6	280.0	286.6	46.6	660
Pc 3	1.2	1.10	.0356	10.3	1,320	25	256	281	940	35	3.7	1,616.0	1,622.6	82.6	310
PJ 4	2.0	1.70	.0667	9.7	2,500	21	428	449	1,770	95	3.7	546.0	552.7	72.7	500
Pt 2	3.2	2.56	.0529	11.0	3,060	47	683	730	2,100	120	3.7	641.6	648.3	48.3	830
Qu 8	6.6	5.51	.0042	11.0	3,660	129	1,408	1,537	1,880	100	3.5	439.7	446.2	66.2	2,050
Qu 10	1.1	1.82	.0172	11.0	985	38	226	264	260	10	3.4	392.5	398.9	38.9	376
Qu 12	6.6	4.74	.0128	10.4	4,100	129	1,408	1,537	720	30	3.6	520.0	526.6	26.6	3,050
Re 5	1.9	1.80	.0313	10.5	1,850	33	405	438	1,025	50	3.6	578.0	584.6	44.6	575
Wa 3	2.3	2.54	.0577	8.8	1,790	23	490	513	1,060	55	3.7	1,316.7	1,323.4	63.4	570
Wa 5	2.4	1.97	.0761	8.8	2,040	24	512	536	1,020	60	3.5	1,618.0	1,624.5	65.5	615
Wa 6	4.7	3.40	.0436	9.1	3,800	39	1,000	1,039	1,670	95	3.6	1,360.2	1,366.0	71.8	1,220
Wa 13	2.1	1.95	.0613	8.8	2,150	21	448	469	790	35	3.9	1,646.4	1,653.3	53.3	449
Wa 14	1.0	1.63	.0464	9.6	1,040	13	218	231	470	25	3.3	1,672.0	1,678.3	52.3	269
We 5	15.6	4.81	.0067	10.1	9,590	103	3,328	3,431	6,800	400	3.9	320.0	326.0	66.0	422
WL 2	17.4	8.43	.0060	9.5	9,200	115	3,712	3,827	3,700	210	3.7	1,016.8	1,023.5	39.5	4,650
Wp 2	2.6	2.26	.0335	9.8	2,700	25	555	580	1,210	65	3.6	811.2	817.8	57.8	712
Wp 5	3.9	3.80	.0201	9.6	3,050	34	832	866	1,600	90	3.6	948.9	955.5	85.5	1,085

1/ Maximum flood control storage = Flood control storage plus surcharge storage.

TABLE R-3
COST OF SMALL DAMS

Prices shown are contract prices for dams constructed as elements of watershed programs.

Dam & Site		Award Date	Cost Index 2/	Embankment, cu. yd.	Total Cost, $ 3/	Total Cost, $ 1/	$/c.y. of Embankment 4/ 3/	$/c.y. of Embankment 4/ 1/
W. Virginia								
Warm Springs	1	Sep 57	737.8	11,697	12,700	13,397	1.08	1.15
" "	2	May 56	688.4	15,930	17,473	19,754	1.10	1.24
" "	3	Nov 55	673.2	32,221	27,626	31,938	0.86	0.99
" "	5	Dec 55	673.1	20,271	16,024	18,528	0.79	0.91
" "	6	Sep 57	737.8	14,424	13,980	14,747	0.97	1.02
" "	7	May 56	688.4	13,328	12,879	14,560	0.97	1.09
" "	9	Sep 56	704.9	16,928	16,941	18,704	1.00	1.10
New Creek	1	May 57	715.7	52,056	31,811	34,592	0.61	0.66
Upper Grave	3	Aug 57	738.6	25,881	24,624	25,947	0.95	1.00
" "	4	Aug 57	738.6	29,515	27,905	29,404	0.95	1.00
Salem Fork	9	Dec 55	673.1	35,455	31,831	36,805	0.90	1.04
" "	11	Jun 56	692.1	14,400	17,330	19,488	1.20	1.35
" "	11A	Sep 54	640.2	16,714	23,071	28,047	1.38	1.68
" "	12	Nov 53	673.2	14,588	14,935	17,266	1.02	1.18
" "	13	Sep 54	640.2	15,236	21,334	25,935	1.40	1.70
" "	14	May 58	751.6	22,449	21,623	22,390	0.96	1.00
" "	15	Jun 56	692.1	12,341	23,571	26,506	1.91	2.15
D&C	3	Apr 58	745.8	57,722	32,648	34,070	0.57	0.59
So. Fork	27	Jun 59		234,000	127,518		0.54	
Marlinton		Jun 59		124,000	73,433		0.59	
Virginia								
Potomac	11	Feb 57	710.1	48,400	29,403	32,226	0.61	0.67
"	19	Nov 56	704.1	58,600	29,000	32,055	0.49	0.55
"	25	May 56	688.4	232,000	77,758	101,521	0.34	0.44
E. Falling	7	May 56	688.4	67,591	42,561	55,568	0.63	0.82
"	15	Feb 56	680.2	56,950	24,960	28,559	0.44	0.50
"	21	May 56	688.4	41,063	25,766	33,640	0.63	0.82
So. River	7	May 57	715.7	96,061	40,293	43,816	0.42	0.46
Maryland								
Little Deer	1	1957	723.8	35,700	40,364	43,402	1.13	1.22
New York								
Pelto		1955	659.7	18,484	18,391	21,697	0.99	1.17
Pylkus		1955	659.7	18,523	19,115	22,551	1.03	1.22
Pennsylvania								
Pa.	418	Jun 59		13,397	20,739		1.55	
"	419	Jun 59		19,900	28,489		1.43	
"	421	Jun 59		10,500	17,022		1.62	

1/ Contract costs escalated to 1 January 1959 price level by use of Engineering News-Record Construction Cost Index, 1913=100, 1 January 1959 = 778.28.

2/ Engineering News-Record Construction Cost Index, 1913=100, for month or year of award.

3/ Price before escalation

4/ Total cost of embankment, outlet and spillways divided by the volume (cubic yards) of embankment.

TABLE R-4
UNIT PRICES BID FOR SMALL DAMS BUILT AS ELEMENTS OF WATERSHED PROGRAMS

These are the low-bid prices for which award was made and the dams were constructed.

Work Item 1/	Unit	Warm Springs 1	Warm Springs 2	Warm Springs 3	Warm Springs 5	Warm Springs 6	Warm Springs 7	Warm Springs 9	New Creek 1	Upper Grave 3	Upper Grave 4	Salem Fork 9	Salem Fork 11	Salem Fork 11A	Salem Fork 12	Salem Fork 13	Salem Fork 14	Salem Fork 15
Embankment	C.Y.	$0.45	$0.37	$0.47	$0.40	$0.45	$0.37	$0.50	$0.45	$0.50	$0.50	$0.47	$0.64	$0.50	$0.47	$0.50	$0.45	$0.64
Clearing & Grubbing	Acre	200.00	125.00	140.00	125.00	200.00	125.00	350.00	225.00	200.00	200.00	150.00	200.00	50.00	150.00	75.00	400.00	200.00
Filter Material	C.Y.	7.00	5.00	6.00	6.00	7.00	5.00	7.00	5.00	6.00	6.00	6.00	10.20		6.00		10.00	10.00
Riprap	Sq.Yd.		5.50	10.00	9.00		5.50	7.50	7.00	12.00	10.00	7.00	11.00	15.00	7.00	15.00		10.00
Type "A" Concrete	C.Y.	80.00	50.00	52.00	50.00	80.00	50.00	60.00	60.00	70.00	70.00	65.00	110.00		65.00		70.00	110.00
Type "B" Concrete	C.Y.	70.00	30.00	40.00		70.00	30.00	60.00	50.00	55.00	55.00	45.00	95.00		45.00		70.00	70.00
Type "C" Concrete	C.Y.	55.00	30.00		25.00	45.00	30.00	50.00	40.00	55.00	55.00	44.00	50.00				45.00	50.00
Reinforcing Steel	Lb.	0.18	0.13	0.12	0.12	0.18	0.13	0.17	0.17	0.18	0.18	0.16	0.15	0.15	0.16	0.15	0.15	0.20
Pipe, 8" B.C.C.M.P. 2/	L.F.	2.84	1.90			2.84	1.90	2.90		2.25	2.25		3.00	3.00		3.00		3.25
Pipe, 6" B.C.C.M.P. 2/	L.F.	2.00				2.00			2.00	2.25	2.25							
Pipe, Perf. 6" B.C.C.M.P. 2/	L.F.	2.32	1.85			2.32	1.85	2.70	2.67	2.75	2.75		2.71				2.50	2.50
Headgate, 8" dia.	L.S.																	
Pipe, 24" Prestressed Conc.	L.F.	17.00				17.00	14.40	16.19	16.00	17.00	17.00		19.00				15.00	
Pipe, 24" Reinf. Conc.	L.F.													9.00		9.00		
Embankment Volume	C.Y.	11,697	15,930	32,221	20,271	14,424	13,328	16,293	52,056	25,881	29,515	35,455	14,400	16,714	14,588	15,236	22,449	12,341
Location of Dam	State	W.Va.	W.Va.	W.Va.	W.Va.	W.Va.	W.Va.	W.Va.	W.Va.	W.Va.	W.Va.	W.Va.	W.Va.	W.Va.	W.Va.	W.Va.	W.Va.	W.Va.
Date of bids, month & year		9/57	5/56	11/55	12/55	9/57	5/56	9/56	5/57	8/57	8/57	12/55	6/56	9/54	11/55	9/54	5/58	6/56
Total Cost per cu.yd. of embankment 3/		1.08	1.10	0.86	0.79	0.97	0.97	1.00	0.61	0.95	0.95	0.90	1.20	1.38	1.02	1.40	0.96	1.91
Total Cost per cu.yd. of embankment 4/		1.15	1.24	0.99	0.91	1.02	1.09	1.10	0.66	1.00	1.00	1.04	1.35	1.68	1.18	1.70	1.00	2.15

1/ Work items include furnishing material, except that earth and rock materials were taken from the spillway area or borrow pits in vicinity of the dam.
2/ B.C.C.M.P. stands for bituminous coated corrugated metal pipe.
3/ The cost per cubic yard of embankment refers to the total construction cost (for all items of work listed) at time of construction divided by the embankment volume. It does not include right-of-way, relocations, engineering or administration.
4/ The total unit costs escalated to January 1959 level, as shown in Table R-3.

TABLE R-4
Sheet 2

TABLE R-4 - Continued
UNIT PRICES BID FOR SMALL DAMS BUILT AS ELEMENTS OF WATERSHED PROGRAMS

These are the low-bid prices for which award was made and the dams were constructed.

Work Item 1/	Unit	D&C 3	South Fork 27	Marlinton 1	Potomac 11	Potomac 19	Potomac 25	E.Falling R. 7	E.Falling R. 15	E.Falling R. 21	South River 7	Little Deer 1	Felto	Fulkus	Lackawaxen 418	Lackawaxen 419	Lackawaxen 421
Embankment	C.Y.	$0.41	$0.60	$0.41	$0.34	$0.29	$0.24	$0.29	$0.22	$0.29	$0.30	$0.30	$0.39	$0.39	$0.80	$0.80	$0.80
Clearing & Grubbing	Acre	100.00	350.00	750.00	300.00	350.00	200.00	395.00	210.00	400.00	250.00		15.00	300.00	400.00	400.00	400.00
Filter Material	C.Y.	4.00	10.00	7.00	6.00	6.00	6.00	6.00	5.00	1.00	5.00	9.50			3.00	3.00	3.00
Riprap	Sq.Yd.		8.00	5.00								8.00	8.00	8.00	2.50	2.50	2.50
Type "A" Concrete	C.Y.	150.00	120.00	80.00								140.00					
Type "B" Concrete	C.Y.	150.00	120.00	75.00	65.00	60.00		65.00	50.00	60.00	55.00	80.00	106.00	113.00	70.00	70.00	70.00
Type "C" Concrete	C.Y.	60.00	100.00	60.00			55.00					35.00			50.00	50.00	50.00
Reinforcing Steel	Lb.	0.16	0.20	0.15	0.20	0.20	0.15	0.20	0.14	0.17	0.20	0.15			0.20	0.20	0.20
Pipe, 8" B.C.C.M.P. 2/	L.F.				2.50				2.50	3.35			6.00	6.00			
Pipe, 6" B.C.C.M.P. 2/	L.F.	4.00	2.00	1.50				3.25			2.00	3.00			3.00	3.00	3.00
Pipe, Perf. 6" B.C.C.M.P. 2/	L.F.	4.00	2.00	2.00													
Headgate, 8" dia.	L.S.	200.00			180.00	200.00	200.00	275.00	200.00	150.00					100.00 (12"dia)	100.00 (12"dia)	100.00 (12"dia)
Pipe, 24" Prestressed Conc.	L.F.	12.00															
Pipe, 24" Reinf. Conc.	L.F.		25.00	16.00											16.00	16.00	16.00
Embankment Volume	C.Y.	57,722	234,670	124,925	48,400	58,600	232,000	67,591	56,950	41,063	96,061	35,700	18,484	18,523	13,397	19,900	10,500
Location of Dam	State	W.Va.	W.Va.	W.Va.	Va.	Va.	Va.	Va.	Va.	Va.	Va.	Md.	N.Y.	N.Y.	Pa.	Pa.	Pa.
Date of bids, month & year		4/58	6/59	6/59	2/57	11/56	5/56	5/56	2/56	3/56	5/57	1957	1955	1955	6/59	6/59	6/59
Total Cost per cu.yd. of embankment 3/		0.57	0.54	0.59	0.61	0.49	0.34	0.63	0.44	0.63	0.42	1.13	0.99	1.03	1.55	1.43	1.62
Total Cost per cu.yd. of embankment 4/		0.59			0.67	0.55	0.44	0.82	0.50	0.82	0.46	1.22	1.17	1.22			

1/ Work items include furnishing material, except that earth and rock materials were taken from the spillway area or borrow pits in vicinity of the dam.
2/ B.C.C.M.P. stands for bituminous coated corrugated metal pipe.
3/ The cost per cubic yard of embankment refers to the total construction cost (for all items of work listed) at time of construction divided by the embankment volume. It does not include right-of-way, relocations, engineering or administration.
4/ The above total unit costs escalated to January 1959 level, as shown in Table R-3.

TABLE B-5
COST ESTIMATES FOR SMALL DAMS PREPARED BY JOINT WORK GROUP

These estimates are based on experienced prices for major control projects - January 1959 price levels

Work Item	Units	Estimated Unit Cost	An 3 Quan.	An 3 $	LE 4 Quan.	LE 4 $	LM 7 Quan.	LM 7 $	Bo 9 Quan.	Bo 9 $	Bo 18 Quan.	Bo 18 $	PJ 4 Quan.	PJ 4 $	Wo 13 Quan.	Wo 13 $	Wo 2 Quan.	Wo 2 $	Br 3 Quan.	Br 3 $
1. Clearing & grubbing	ac.	$600.00	15	9,000	9.4	5,640	13.8	8,280	8.2	4,920	5.6	3,360	5	3,000	3.4	2,040	7.6	4,560	1	600
2. Embankment 1/	c.y.	from 1.06 to 1.41	535,440 1.00 2/ (0.78)	536,850 (417,663)	427,405 1.07 2/ (0.80)	457,323 (342,922)	372,850 1.09 2/ (0.82)	406,406 (304,805)	290,060 1.13 2/ (0.85)	327,768 (265,825)	194,169 1.19 2/ (0.89)	231,061 (173,296)	138,150 1.24 2/ (0.93)	171,306 (128,480)	123,460 1.26 2/ (0.95)	155,560 (116,670)	103,850 1.28 2/ (0.96)	132,928 (99,696)	13,790 1.41 2/ (1.06)	19,308 (14,560)
3. Furnish & place riprap	c.y.	9.00	1,220	10,980	1,000	9,000	1,520	13,680	900	8,100	600	5,400	580	5,220	720	6,480	550	4,950	130	1,170
4. Furnish & place conc. pipe																				
24" I.D.	l.f.	13.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	220	2,860
30" I.D.	l.f.	18.00	-	-	-	-	-	-	-	-	450	8,100	450	8,100	400	7,200	352	6,336	-	-
42" I.D.	l.f.	30.00	-	-	580	17,400	-	-	480	14,400	-	-	-	-	-	-	-	-	-	-
48" I.D.	l.f.	37.00	650	24,050	-	-	550	20,350	-	-	-	-	-	-	-	-	-	-	-	-
5. Conc. in riser	c.y.	80.00	20.75	1,660	17.7	1,416	21.95	1,756	20	1,600	14.85	1,188	12	960	12	960	15.1	1,208	7.2	576
6. Conc. in collars	c.y.	50.00	26.8	1,340	25.1	1,255	26.8	1,340	24	1,200	23.4	1,170	23	1,150	24	1,200	23.4	1,170	22.8	1,140
7. Slide gate 2' x 2'	lb.	0.25	700	175	700	175	700	175	700	175	700	175	700	175	700	175	700	175	700	175
8. Reinf. steel	lb.	0.22	4,060	893	4,000	880	4,390	966	8,500	1,870	3,443	757	3,150	693	3,150	693	3,465	762	4,070	895
9. Trash rack, steel	lb.	0.60	214	128	160	96	214	128	160	96	246	148	170	102	166	100	200.5	120	133.7	80
10. Salvage & place topsoil	c.y.	1.10	12,100	13,310	7,580	8,338	11,130	12,243	6,615	7,276	4,520	4,972	4,030	4,433	2,740	3,014	6,130	6,743	807	888
TOTAL COST			$618,394		$501,523		$465,324		$367,405		$256,331		$195,130		$177,422		$158,952		$27,772	
TOTAL COST - ADJUSTED			($479,179)		($387,192)		($363,723)		($285,462)		($198,566)		($152,313)		($138,532)		($125,720)		($22,926)	
Total cost per cu. yd. of embankment			$1.16		$1.17		$1.25		$1.27		$1.32		$1.41		$1.44		$1.53		$2.02	
Total cost per cu. yd. of embankment - adjusted			($0.90)		($ 0.91)		($0.98)		($0.98)		($1.02)		($1.10)		($1.12)		($1.21)		($1.67)	

1/ The price for embankment includes excavating "common" material from the spillway area or from a borrow area near the dam, hauling, placing and compacting.
2/ Embankment unit price for each site.

NOTE: The embankment prices (not the total cost) for each site, based on experience with major control projects, have been adjusted downward 25 percent to take into account the probable use of small contracting firms and the simplified nature of: (1) the overall project, (2) the contract specifications, and (3) inspection and control. The adjusted unit prices for embankment are shown in parentheses. The total cost of the embankment, the "TOTAL COST - ADJUSTED," and the "Total cost per cu. yd. of embankment - adjusted," based on the adjusted unit price for embankment, are also shown in parentheses.

TABLE R-6

SUMMARY OF ESTIMATES AND COSTS FOR SMALL DAMS

Data from Tables 3, 4 and 5, and based on January 1959 price levels.

Dam & State	Embankment Vol., c.y.	Cost or Estimate	$/c.y. of Embankment
An 3, N.Y.	535,440	1/	0.90
LE 4, N.Y.	427,405	1/	0.91
LM 7, N.Y.	372,850	1/	0.98
De 9, N.Y.	290,060	1/	0.98
So.Fork, 27, W.Va.	234,000	2/	0.54
Potomac 25, Va.	232,000	2/	0.44
Dp 18, N.Y.	194,169	1/	1.02
PJ 4, Pa.	138,150	1/	1.10
Marlinton 1, W.Va.	124,000	2/	0.59
Wa 13, N.Y.	123,460	1/	1.12
Wp 2, N.J.	103,850	1/	1.21
So. River 7, Va.	96,061	2/	0.46
E. Falling R. 7, Va.	67,591	2/	0.82
Potomac 19, Va.	58,600	2/	0.55
D&C 3, W. Va.	57,722	2/	0.59
E. Falling R. 15, Va.	56,950	2/	0.50
New Creek 1, W. Va.	52,056	2/	0.66
Potomac 11, Va.	48,400	2/	0.67
E. Falling R. 21, Va.	41,063	2/	0.82
Little Deer 1, Md.	35,700	2/	1.22
Salem Fork 9, W. Va.	35,455	2/	1.04
Warm Springs 3, W. Va.	32,221	2/	0.99
Upper Grave 4, W. Va.	29,515	2/	1.00
Upper Grave 3, W. Va.	25,881	2/	1.00
Salem Fork 14, W. Va.	22,449	2/	1.00
Warm Springs 5,W. Va.	20,271	2/	0.91
Pa. 419, Pa.	19,900	2/	1.43
Pylkus, N.Y.	18,523	2/	1.22
Pelto, N.Y.	18,484	2/	1.17
Warm Springs 9, W. Va.	16,928	2/	1.10
Salem Fork 11A, W. Va.	16,714	2/	1.68
Warm Springs 2, W. Va.	15,930	2/	1.24
Salem Fork 13, W. Va.	15,236	2/	1.70
Salem Fork 12, W. Va.	14,588	2/	1.18
Warm Springs 6, W. Va.	14,424	2/	1.02
Salem Fork 11, W. Va.	14,400	2/	1.35
Dy 3, Pa.	13,750	1/	1.67
Pa 418, Pa.	13,397	2/	1.55
Warm Springs 7, W. Va.	13,328	2/	1.09
Salem Fork 15, W. Va.	12,341	2/	2.15
Warm Springs 1, W. Va.	11,697	2/	1.15
Pa. 421, Pa.	10,500	2/	1.62

1/ Estimated cost (adjusted) from Table R-5.

2/ Actual price paid for construction, escalated to January 1959 price level, shown on Table R-3.

TABLE R-7

REPRESENTATIVE COST FOR RECREATION DEVELOPMENT
AT TWO TYPICAL SITES FOR SMALL DAM PROJECTS

DESIGN CRITERIA		SITE NO. 2		SITE NO. 3	
Total Annual Attendance		50,000		30,000	
Design Load 1/		1,150		700	
FIRST COST					
Facilities Item	Unit 1/	No. Units	Total Cost	No. Unit	Total Cost
Picnicking	Each	23	$ 9,200	14	$ 5,600
Picnic Shelters	Each	1	5,000	1	5,000
Swimming	Sq. ft.	31,600	8,000	19,300	4,800
Changehouse	L.S.	--	20,000	--	15,000
Boating	Each	1	18,000	1	10,000
Camping	Each	20	25,000	15	18,800
Parking	Each	230	46,000	140	28,000
Roads	Mile	1	20,000	1	20,000
Water Supply	Each	15	15,000	10	10,000
Sanitary	Each	4	30,000	2	15,000
Walks & Trails	Mile	0.5	1,300	0.4	1,000
Signs & Markers	L.S.	--	300	--	200
Misc. Landscaping	L.S.	--	1,700	--	1,100
Admin. Area	L.S.	--	25,000	--	20,000
Sub-Total			224,500		154,500
Plan., Eng. & Contingencies 25%			56,100		38,600
Total Cost Facilities			280,600		193,100
Land	Acre	670 @$150. 2/	100,500	138 @$150. 2/	20,700
Total Cost Facilities & Land			381,100		213,800
ANNUAL CHARGES					
Operation & Maintenance 3/			2,500		1,500
Invest. Amortized (50 yrs. @ 2-1/2%)			13,400		7,500
Major Replacement (1/3 Facil. 25 yrs.)			1,800		1,300
Total Annual Charges			17,700		10,300

1/ Defined in Appendix W
2/ Derived from average cost per acre at all sites studied.
3/ $0.05 per visitor-day.

TABLE R-8

SMALL HEADWATER STREAMS IN THE DELAWARE RIVER BASIN WITH LOCAL REACHES OF MODERATE TO HIGH FLOOD DAMAGE POTENTIAL

Sub-basin	Stream	Tributary of	Major Damage Reach	Average Annual Damages: Natural - Without Protection	Modified by Watershed Plans	Modified by 39 Proposed Reservoirs
1	Wright Brook	W.Br. Delaware River	Bloomville, N. Y.	$1,200	$1,200	$1,200
	Steele Brook	W.Br. Delaware River	Delhi, N. Y.	500	500	500
	East Brook	W.Br. Delaware River	Walton, N. Y.	32,900	32,900	24,480
	West Brook	W.Br. Delaware River	Walton, N. Y.	28,480	28,480	1,430
	Oguaga Creek	W.Br. Delaware River	Sanford Town, N. Y.	2,840	2,840	2,840
	Brush Brook	W.Br. Delaware River	Bovina Center, N. Y.	850	850	850
	Total			66,770	66,770	31,300
2	Downs Brook	E.Br. Delaware River	Downsville, N. Y.	11,650	11,650	11,650
	L.Beaver Kill-Willowemoc	Beaver Kill	Livingston Manor, N. Y.	17,280	17,280	17,280
	Beaver Kill	E.Br. Delaware River	Roscoe, Rockland, N. Y.	6,240	6,240	6,240
	Total			35,170	35,170	35,170
3	N.Br. Callicoon Creek	Callicoon Creek	Hortonville North Branch, N. Y.	31,980	31,980	11,200
	N.Br. Callicoon Creek	Callicoon Creek	Callicoon Center, N. Y.	10,200	10,200	10,200
	E.Br. Callicoon Creek	Callicoon Creek	Jeffersonville, N. Y.			
	Panther Rock Brook	E.Br. Callicoon Creek	Youngsville, N. Y. - Rural area	1,320	1,320	1,320
	Wallenpaupack Creek	Lackawaxen River	Greentown, S. Sterling, Newfoundland, Pa.	188,000	22,700	22,700
	Middle Creek	Lackawaxen River	Upstream from Hawley, Pa.	10,000	10,000	10,000
	Other Lackawaxen Tribs.	Lackawaxen River	Between Hawley & Honesdale, Pa.	30,160	16,620	16,620
	Unnamed stream	Neversink River	Huguenot, N. Y.	800	800	800
	Total			272,460	93,620	72,840

TABLE R-8 - Continued
SMALL HEADWATER STREAMS IN THE DELAWARE RIVER BASIN WITH
LOCAL REACHES OF MODERATE TO HIGH FLOOD DAMAGE POTENTIAL

Sub-basin	Stream	Tributary of	Major Damage Reach	Average Annual Damages: Natural - Without Protection	Average Annual Damages: Modified by Watershed Plans	Average Annual Damages: Modified by 39 Proposed Reservoirs
4	Saw Kill	Delaware River	Milford, Pa.	$4,640	$4,640	$4,640
	Dwarfs Kill	Delaware River	Dingmans Twp., Pa.	2,500	2,500	2,500
	Paulins Kill	Delaware River	Blairsville, Branchville, N. J.	21,520	850	850
	Brodhead Creek	Delaware River	Canadensis, Buck Hill Falls, Pa.	69,520	69,520	41,720
	Brodhead Creek	Delaware River	Canadensis to Stites Bridge, Pa.	38,800	38,800	20,900
	Brodhead Creek	Delaware River	Stites Bridge to Stroudsburg, Pa.	91,200	91,200	33,700
	Rattlesnake & Mill Creeks	Brodhead Creek	Mountain Home, Pa.	25,300	25,300	3,400
	Paradise Creek	Brodhead Creek	Paradise Valley, Pa.	74,600	74,600	11,800
	Analomink Creek	Brodhead Creek	Henryville, Parkside to Stites Bridge, Pa.	76,100	76,100	8,700
	Swiftwater & Paradise Creeks	Brodhead Creek	E.Swiftwater to Parkside, Pa.	57,200	57,200	2,200
	Pocono Creek	Brodhead Creek	Bartonville, Stroud Twp., Pa.	75,720	75,720	20,080
	Pocono Creek	Brodhead Creek	Tannersville, Pocono Twp., Pa.	53,280	53,280	8,880
	McMichael Creek	Brodhead Creek	Brodheadsville, McMichael, Sciota, Pa.	5,740	5,740	5,740
	Appenzell Creek	McMichaels Creek	Appenzell, Snydersville, Kellersville, Pa.	7,370	7,370	7,370
	Kettle Creek	McMichaels Creek	North of Snydersville, Pa.	6,810	6,810	6,810
	Total			610,300	589,630	179,290

TABLE R-8 - Continued
SMALL HEADWATER STREAMS IN THE DELAWARE RIVER BASIN WITH
LOCAL REACHES OF MODERATE TO HIGH FLOOD DAMAGE POTENTIAL

Sub-basin	Stream	Tributary of	Major Damage Reach	Average Annual Damages: Natural - Without Protection	Average Annual Damages: Modified by Watershed Plans	Average Annual Damages: Modified by 39 Proposed Reservoirs
5	E.Br. Monocacy Creek	Lehigh River	Bath Jct., Pa. - Cement Plants	$67,190	$67,190	$56,860
	Mauch Chunk Creek	Lehigh River	Jim Thorpe, Pa.	24,590	24,590	6,800
	Buckwha Creek	Aquashicola Creek	Little Gap, Palmerton, Pa.	40,000	40,000	40,000
	Total			131,780	131,780	103,660
6	Bushkill Creek	Delaware River	Stockerton, Pa.-Roads & Bridges	86,760	86,760	52,740
	Little Martins Creek	Martins Creek	Martins Creek, Pa.	22,600	22,600	16,950
	Total			109,360	109,360	69,690
7	Trib. Tacony Creek	Delaware River	N.E. Philadelphia, Pa.	6,200	6,200	450
	Little Neshaminy Creek & Lower Neshaminy Creek	Neshaminy Creek	Neshaminy, Hulmville, Pa.	54,890	54,890	32,030
	Upper Neshaminy Creek	Neshaminy Creek	Chalfont, Pa.	54,440	54,440	54,440
	Total			115,530	115,530	86,920
8	Little Schuylkill River	Schuylkill River	Tamaqua, Reynolds, New Ringgold, Pa.	119,850	8,070	8,070
	Unami Creek	Perkiomen Creek	Finland, Pa.	500	500	500
	Perkiomen Creek	Schuylkill River	Zieglersville, Pa.-Rural homes	2,200	2,200	2,200
	Tulpehocken Creek	Schuylkill River	Bernville, Pa.	3,000	3,000	3,000
	Wissahickon Creek	Schuylkill River	Fort Washington, Fairmount Park, Pa.	38,970	38,970	27,920
	Stony Creek	Schuylkill River	Norristown, Pa.	21,000	21,000	8,240
	Total			185,520	73,740	49,930
9	Brandywine Creek	Christina River	Coatesville, Downingtown, Pa.	241,960	59,900	59,900
	Total			241,960	59,900	59,900
				1,768,850	1,275,500	688,700

TABLE R-9

EXAMPLE OF GENERALIZED PROCEDURE FOR DETERMINING AVERAGE ANNUAL FLOOD DAMAGES AND BENEFITS FOR TYPICAL REACH BELOW PROJECT LM-2

Types of Flood Damages in Reaches	Degree of Flooding	Total Property Valuation	Average Annual Physical Damages: Concen-trated	Average Annual Physical Damages: Scat-tered 1/	Average Annual Damages: Total Physical	Average Annual Damages: Business Loss & Emergency	Average Annual Damages: Total	Average Annual Benefits: Physical	Average Annual Benefits: Business Loss & Emergency	Average Annual Benefits: Total
12-Residences	1st Floor	$ 112,500	$2,250	$ 450	$ 2,700	$ 410	$ 3,110			
22-Residences	Basement	203,000	2,030	410	2,440	370	2,810			
Residental Total					5,140	780		$ 3,340	$ 510	$ 3,850
2-Manufacturing	1st Floor	83,500	1,670	330	2,000	500	2,500			
4-Manufacturing	1st Floor	98,400	1,970	390	2,360	590	2,950			
Manufacturing & Retailing Total					4,360	1,090		2,830	710	3,540
Agriculture	-	-	220	40	260	40	300	170	25	195
5-Bridges	-	392,000	7,840	1,570	9,410	2,350	11,760			
Roads	-	-	3,840	770	4,610	1,160	5.770			
Roads, Railroads & Bridges Total					14,020	3,510		9,110	2,280	11,390
Sediment & Erosion	-	-	1,620	320	1,940	-	1,940	1,260	-	1,260
Emergency	-	-	-	-	-	840	840	-	545	545
TOTALS	-	-	21,440	4,280	25,720	6,260	31,980	16,710	4,070	20,780

Area controlled	13.8 sq. mi.
Total area above damage reach	34.3 sq. mi.
Percent area controlled	40.2
Percent damage reduction	65.0

1/ Scattered annual physical damages in sparsely developed areas of the reach are estimated at 20% of the concentrated annual damages in the reach.

TABLE R-10
DETAILED COST ESTIMATE
PARKSIDE PROJECT (Pc 8)

Description	Unit	Unit Price	Quantity	Cost
Embankment	c.y.	$0.97	397,800	$385,870
Filter Material	c.y.	2.00	36,200	72,400
Riprap	c.y.	3.00	1,000	3,000
Concrete, Floor	c.y.	25.00	2,080	52,000
Concrete, Walls	c.y.	45.00	1,600	72,000
Concrete, Cradle	c.y.	35.00	210	7,400
Cement	bbl.	6.00	5,800	35,000
Reinforcing Steel	lb.	0.18	200,000	36,000
Backfill	c.y.	1.00	1,000	1,000
Fencing & Seeding	job	l.s.	--	3,000
Subtotal				667,670
Contingencies 20%				133,530
Subtotal				801,200
Engineering & Administration 25%				200,300
Subtotal				1,001,500
Land	Acre	150.	138	20,700
Total				1,022,200

TABLE R-11
DETAILED COST ESTIMATE
SWIFTWATER PROJECT (Re9)

Description	Unit	Unit Price	Quantity	Cost
Embankment, Earth	c.y.	$0.95	431,000	$409,450
Embankment, Rock	c.y.	2.80	61,000	170,800
Filter Material	c.y.	2.00	44,000	88,000
Riprap	c.y.	3.00	1,000	3,000
Concrete, Cradle	c.y.	35.00	230	8,050
Cement	bbl.	6.00	290	1,750
Reinforcing Steel	lb.	0.18	16,100	2,900
Backfill	c.y.	1.00	1,100	1,100
Fencing & Seeding	job	l.s.	--	3,000
Subtotal				688,050
Contingencies 20%				137,610
Subtotal				825,660
Engineering & Design 25%				206,420
Subtotal				1,032,080
Land	Acre	150	114	17,100
Relocations	Mile	75,000	0.4	30,000
Total				1,079,180

TABLE R-12
DETAILED COST ESTIMATE
JIM THORPE PROJECT (Hz 6)

Description	Unit	Unit Cost	Quantity	Cost
Embankment, Earth	c.y.	$1.10	161,270	$177,400
Riprap	c.y.	4.00	1,500	6,000
Concrete, Spillway	c.y.	40.00	2,010	80,400
Cement	bbl.	6.00	2,520	15,120
Reinforcing Steel	lb.	0.18	80,400	14,470
Fencing & Seeding	job	l.s.	--	3,000
Subtotal				296,390
Contingencies 20%				59,280
Subtotal				355,670
Engineering & Administration 25%				88,920
Subtotal				444,590
Land	Acre	150	162	24,300
Total				468,890

TABLE R-13

DISCHARGES FOR SELECTED FREQUENCIES OF OCCURRENCE, WITH AND WITHOUT PROJECTS AT TYPICAL CONTROL POINTS

Control Points	Drainage Area Controlled (%)	Average Recurrence Interval (years)	Peak Discharge without Dams (cfs)	Peak Discharge with Dams (cfs)	Reduction in Peak Discharge (%)
Canadensis, Pa.	23.5	5	3,230	2,600	19.5
Brodhead Creek		10	4,200	3,380	19.8
(DA = 29.0 sq.mi.)		25	5,850	4,650	20.7
		50	7,600	6,030	20.7
		100	10,300	8,300	19.4
Paradise Valley, Pa.	63.6	5	1,450	650	55.1
Paradise Creek		10	1,880	840	55.3
(DA = 12.6 sq.mi.)		25	2,600	1,130	56.5
		50	3,450	1,500	56.5
		100	4,700	2,350	50.0
Tannersville, Pa.	61.1	5	1,900	860	54.7
Pocono Creek		10	2,500	1,130	54.8
(DA = 22.3 sq.mi.)		25	3,450	1,610	53.3
		50	4,600	2,200	52.2
		100	6,400	3,150	50.8
Stroudsburg, Pa. (nr)	50.9	5	3,800	2,120	44.2
Pocono Creek		10	4,900	3,050	37.8
(DA = 49.1 sq.mi.)		25	6,800	5,000	26.5
		50	8,900	6,900	22.5
		100	12,100	9,600	21.6
Jim Thorpe, Pa.	85.0	5	465	50	89.2
Mauch Chunk Creek		10	670	90	86.6
(DA = 8.0 sq.mi.)		25	1,030	150	85.4
		50	1,540	240	84.4
		100	2,350	580	75.3

TABLE R-14
STORAGE CAPACITIES AND COSTS FOR 39 SELECTED PROJECTS

Site	Stream	Location	Drainage Area (sq. mi.)	Storage Capacity: Sediment (ac.-ft.)	Storage Capacity: Flood Control (ac.-ft.)	Storage Capacity: Total (ac.-ft.)	Total Cost (dollars)	Cost per ac.-ft. of Capacity (dollars)
Wa-16	West Brook	Delaware Co., N.Y.	21.5	140	4,587	4,727	399,160	84
Oa-2	East Brook	Delaware Co., N.Y.	3.9	35	832	867	127,750	146
Lm-2	N.Br. Callicoon Creek	Sullivan Co., N.Y.	13.8	96	2,944	3,040	347,420	114
Pc-1	Devils Hole Creek	Monroe Co., Pa.	4.8	40	1,022	1,062	383,460	361
Pc-2	Rattlesnake Creek	Monroe Co., Pa.	2.6	26	554	580	188,480	325
Pc-5	Trib. Buck Hill Creek	Monroe Co., Pa.	1.5	20	320	340	194,790	572
Pc-6	Trib. Paradise Creek	Monroe Co., Pa.	1.0	14	213	227	78,200	344
Pc-7	Trib. Rattlesnake Creek	Monroe Co., Pa.	1.5	20	320	340	134,260	395
Pc-8	Cranberry Creek	Monroe Co., Pa.	6.8	52	2,218	2,270	1,022,200	450
Pc-9	Swiftwater Creek	Monroe Co., Pa.	9.7	71	3,279	3,350	1,079,180	322
Pc-10	Forest Hill Run	Monroe Co., Pa.	3.3	31	703	734	210,230	286
Pc-11	Tank Creek	Monroe Co., Pa.	2.2	23	469	492	183,740	373
Bu-1	Leavitt Branch	Monroe Co., Pa.	5.3	43	1,129	1,172	369,680	315
Bu-5	Poplar Run	Monroe Co., Pa.	2.4	24	511	535	140,690	263
Bu-6	Pine Mountain Run	Monroe Co., Pa.	2.7	27	575	602	206,850	344
Bu-7	Trib. Brodhead Creek	Monroe Co., Pa.	1.2	15	256	271	100,880	372
Bu-10	Trib. Brodhead Creek	Monroe Co., Pa.	2.5	25	532	557	169,710	305
Pc-12	Scot Run	Monroe Co., Pa.	1.7	19	362	381	121,630	319
Pc-13	Trib. Scot Run	Monroe Co., Pa.	1.4	17	298	315	133,610	424
Pc-14	Pocono Creek	Monroe Co., Pa.	5.6	45	1,193	1,238	384,880	311
Pc-15	Swamp Run	Monroe Co., Pa.	2.5	25	532	557	187,250	336
Pc-16	Trib. Pocono Creek	Monroe Co., Pa.	1.2	15	256	271	108,980	402
Pc-17	Trib. Pocono Creek	Monroe Co., Pa.	1.2	15	256	271	88,740	327
Pc-18	Reeders Run	Monroe Co., Pa.	3.5	32	746	778	263,500	339
Pc-19	Rocky Run	Monroe Co., Pa.	2.4	24	511	535	164,190	307
Pc-20	Bulgers Run	Monroe Co., Pa.	1.7	19	362	381	134,430	353
Pc-21	Cranberry Creek	Monroe Co., Pa.	2.1	22	447	469	176,910	377
Pc-22	Wigwam Creek	Monroe Co., Pa.	1.7	19	362	381	144,930	380
WG-1	E. Br. Monocacy Creek	Northampton Co., Pa.	2.0	34	427	461	197,700	429
Ms-6	Mauch Chunk Creek	Carbon Co., Pa.	6.8	80	1,520	1,600	468,890	307
DG-1	Little Martins Creek	Northampton Co., Pa.	2.4	39	512	551	157,200	285
WG-5	Bushkill Creek	Northampton Co., Pa.	24.8	248	5,291	5,540	362,770	65
Gt-7	Trib. Tacony Creek	Montgomery Co., Pa.	1.9	52	404	456	120,290	264
Gt-10	Little Neshaminy Creek	Bucks Co., Pa.	12.0	210	2,560	2,770	333,600	120
Gt-11	Park Creek	Montgomery Co., Pa.	10.9	195	2,325	2,520	227,240	90
Mt-1	W. Br. Stony Creek	Montgomery Co., Pa.	2.1	56	448	504	151,850	301
Mt-2	Trib. Stony Creek	Montgomery Co., Pa.	2.4	61	512	573	112,970	197
Gt-4	Trib. Sandy Run	Montgomery Co., Pa.	1.9	52	405	457	143,880	315
Gt-13	Trib. Sandy Run	Montgomery Co., Pa.	1.0	37	213	250	104,280	417
	Totals		179.9	2,022	40,336	42,365	9,626,400	

TABLE R-15
ESTIMATED COST FOR 39 SELECTED PROJECTS

Site	Stream	Location	Earth Embankment (cu. yds.)	Federal Costs: Construction Costs: Unit Cost (per cu.yd.)	Construction Costs: Project Cost	Construction Costs: Seeding & Fencing	Construction Costs: Total	Contingencies	Engineering	Total Federal Costs	Non-Federal Costs: Lands, Easements & Rights of Way	Total Project Costs
Wa-16	West Brook	Delaware Co., N.Y.	227,084	$1.05	$238,440	$3,000	$241,440	$48,290	$72,430	$362,160	$37,000	$399,160
On-2	East Brook	Delaware Co., N.Y.	50,000	1.31	65,500	3,000	68,500	13,700	20,550	102,750	25,000	127,750
LM-2	N.Br. Callicoon Creek	Sullivan Co., N.Y.	187,615	1.08	202,620	3,000	205,620	41,120	61,680	308,420	39,000	347,420
Pc-1	Devils Hole Creek	Monroe Co., Pa.	220,800	1.05	231,840	3,000	234,840	46,970	70,450	352,260	31,200	383,460
Pc-2	Rattlesnake Creek	Monroe Co., Pa.	93,600	1.19	111,380	3,000	114,380	22,880	34,320	171,580	16,900	188,480
Pc-5	Trib. Buck Hill Creek	Monroe Co., Pa.	102,000	1.18	120,360	3,000	123,360	24,670	37,010	185,040	9,750	194,790
Pc-6	Trib. Paradise Creek	Monroe Co., Pa.	32,000	1.40	44,800	3,000	47,800	9,560	14,340	71,700	6,500	78,200
Pc-7	Trib. Rattlesnake Creek	Monroe Co., Pa.	63,000	1.27	80,010	3,000	83,010	16,600	24,900	124,510	9,750	134,260
Pc-8	Cranberry Creek	Monroe Co., Pa.	434,000	(Details in Table R-10)			667,670	133,530	200,300	1,001,500	20,700	1,022,200
Pc-9	Swiftwater Creek	Monroe Co., Pa.	536,000	(Details in Table R-11)			688,050	137,610	206,420	1,032,080	47,100	1,079,180
Pc-10	Forest Hill Run	Monroe Co., Pa.	105,000	1.17	122,850	3,000	125,850	25,170	37,760	188,780	21,450	210,230
Pc-11	Tank Creek	Monroe Co., Pa.	92,400	1.19	109,960	3,000	112,960	22,590	33,890	169,440	14,300	183,740
Bu-1	Leavitt Branch	Monroe Co., Pa.	208,000	1.06	220,480	3,000	223,480	44,700	67,050	335,230	34,450	369,680
Bu-5	Poplar Run	Monroe Co., Pa.	63,800	1.26	80,390	3,000	83,390	16,680	25,020	125,090	15,600	140,690
Bu-6	Pine Mountain Run	Monroe Co., Pa.	105,300	1.17	123,200	3,000	126,200	25,240	37,860	189,300	17,550	206,850
Bu-7	Trib. Brodhead Creek	Monroe Co., Pa.	44,400	1.33	59,050	3,000	62,050	12,410	18,620	93,080	7,800	100,880
Bu-10	Trib. Brodhead Creek	Monroe Co., Pa.	81,400	1.22	99,310	3,000	102,310	20,460	30,690	153,460	16,250	169,710
Pc-12	Scot Run	Monroe Co., Pa.	54,400	1.30	70,720	3,000	73,720	14,740	22,120	110,580	11,050	121,630
Pc-13	Trib. Scot Run	Monroe Co., Pa.	63,000	1.27	80,010	3,000	83,010	16,600	24,900	124,510	9,100	133,610
Pc-14	Pocono Creek	Monroe Co., Pa.	218,400	1.05	229,320	3,000	232,320	46,460	69,700	348,480	36,400	384,880
Pc-15	Swamp Run	Monroe Co., Pa.	92,500	1.20	111,000	3,000	114,000	22,800	34,200	171,000	16,250	187,250
Pc-16	Trib. Pocono Creek	Monroe Co., Pa.	49,200	1.31	64,450	3,000	67,450	13,490	20,240	101,180	7,800	108,980
Pc-17	Trib. Pocono Creek	Monroe Co., Pa.	37,200	1.37	50,960	3,000	53,960	10,790	16,190	80,940	7,800	88,740
Pc-18	Reeders Run	Monroe Co., Pa.	140,000	1.125	157,500	3,000	160,500	32,100	48,150	240,750	22,750	263,500
Pc-19	Rocky Run	Monroe Co., Pa.	78,100	1.23	96,060	3,000	99,060	19,810	29,720	148,590	15,600	164,190
Pc-20	Bulgers Run	Monroe Co., Pa.	62,900	1.26	79,250	3,000	82,250	16,450	24,680	123,380	11,050	134,430
Pc-21	Cranberry Creek	Monroe Co., Pa.	88,200	1.20	105,840	3,000	108,840	21,770	32,650	163,260	13,650	176,910
Pc-22	Wigwam Creek	Monroe Co., Pa.	69,000	1.25	86,250	3,000	89,250	17,850	26,780	133,880	11,050	144,930
WG-1	E. Br. Monocacy Creek	Northampton Co., Pa.	98,684	1.19	117,430	3,000	120,430	24,090	36,130	180,650	17,050	197,700
Hz-6	Mauch Chunk Creek	Carbon Co., Pa.	161,270	(Details in Table R-12)			296,390	59,280	88,920	444,590	24,300	468,890
DG-1	Little Martins Creek	Northampton Co., Pa.	78,130	1.23	96,100	3,000	99,100	19,820	29,730	148,650	8,550	157,200
WG-5	Bushkill Creek	Northampton Co., Pa.	207,118	1.06	219,550	3,000	222,550	44,510	66,760	333,820	28,950	362,770
Gt-7	Trib. Tacony Creek	Montgomery Co., Pa.	31,039	1.41	43,760	3,000	46,760	9,350	14,030	70,140	50,150	120,290
Gt-10	Little Neshaminy Creek	Bucks Co., Pa.	190,560	1.07	203,900	3,000	206,900	41,380	62,070	310,350	23,250	333,600
Gt-11	Park Creek	Montgomery Co., Pa.	35,135	1.38	48,490	3,000	51,490	10,300	15,450	77,240	150,000	227,240
Nt-1	W. Br. Stony Creek	Montgomery Co., Pa.	76,290	1.22	93,070	3,000	96,070	19,210	28,820	144,100	7,750	151,850
Nt-2	Trib. Stony Creek	Montgomery Co., Pa.	49,478	1.31	64,820	3,000	67,820	13,560	20,340	101,720	11,250	112,970
Gt-4	Trib. Sandy Run	Montgomery Co., Pa.	69,002	1.25	86,250	3,000	89,250	17,850	26,780	133,880	10,000	143,880
Gt-13	Trib. Sandy Run	Montgomery Co., Pa.	45,000	1.33	59,850	3,000	62,850	12,570	18,860	94,280	10,000	104,280
												9,626,400

TABLE R-16
ESTIMATED ANNUAL BENEFITS AND COSTS FOR 39 SELECTED PROJECTS

			Annual Flood Control Benefits								Annual Costs		
Site	Stream	Location	Agri-cultural	Manufac-turing & Retailing	Resi-dential	Roads, Railroads & Bridges	Sediment and Erosion	Business Loss and Emergency	Total	Total Project Costs	Amorti-zation of Costs	Operation and Main-tenance	Total
Wa-16	West Brook	Delaware Co., N.Y.	$4,890	$4,940	$460	$11,740		$5,020	$27,050	$399,160	$14,070	$300	$14,370
On-2	East Brook	Delaware Co., N.Y.	1,590	1,610	2,760	900		1,560	8,420	127,750	4,500	300	4,800
LM-2	N.Br. Callicoon Creek	Sullivan Co., N.Y.	170	2,830	3,340	9,110	$1,260	4,070	20,780	347,420	12,250	300	12,550
Pc-1	Devils Hole Creek	Monroe Co., Pa.	220	570	1,070	37,170		9,630	48,660	383,460	13,520	300	13,820
Pc-2	Rattlesnake Creek	Monroe Co., Pa.	410	380	2,930	11,640		2,930	18,290	188,480	6,650	300	6,950
Pc-5	Trib. Buck Hill Creek	Monroe Co., Pa.	250	2,710	1,390	2,170		1,660	8,180	194,790	6,870	300	7,170
Pc-6	Trib. Paradise Creek	Monroe Co., Pa.	50	130	250	8,010		2,090	10,530	78,200	2,760	300	3,060
Pc-7	Trib. Rattlesnake Creek	Monroe Co., Pa.	230	220	1,690	6,730		1,690	10,560	134,260	4,730	300	5,030
Pc-8	Cranberry Creek	Monroe Co., Pa.	440	1,710	3,670	27,800		8,150	41,770	1,022,200	36,040	300	36,340
Pc-9	Swiftwater Creek	Monroe Co., Pa.	570	1,500	4,360	50,340		13,810	70,580	1,079,180	38,050	300	38,350
Pc-10	Forest Hill Run	Monroe Co., Pa.	180	460	1,400	16,520		4,520	23,080	210,230	7,410	300	7,710
Pc-11	Tank Creek	Monroe Co., Pa.	110	280	530	17,480		4,540	22,940	183,740	6,480	300	6,780
Bu-1	Leavitt Branch	Monroe Co., Pa.	970	10,080	5,210	8,250		6,220	30,730	369,680	13,030	300	13,330
Bu-5	Poplar Run	Monroe Co., Pa.	680	310	600	3,320		1,080	5,990	140,690	4,960	300	5,260
Bu-6	Pine Mountain Run	Monroe Co., Pa.	840	380	730	4,070		1,320	7,340	206,850	7,290	300	7,590
Bu-7	Trib. Brodhead Creek	Monroe Co., Pa.	550	190	460	2,500		820	4,520	100,880	3,560	300	3,860
Bu-10	Trib. Brodhead Creek	Monroe Co., Pa.	420	720	530	4,100		1,360	7,130	169,710	5,980	300	6,280
Pc-12	Scot Run	Monroe Co., Pa.	400	1,050	600	4,370		1,520	7,940	121,630	4,290	300	4,590
Pc-13	Trib. Scot Run	Monroe Co., Pa.	330	820	500	3,740		1,300	6,690	133,610	4,710	300	5,010
Pc-14	Pocono Creek	Monroe Co., Pa.	1,300	3,480	2,030	14,760		5,120	26,690	384,880	13,570	300	13,870
Pc-15	Swamp Run	Monroe Co., Pa.	580	1,550	900	6,500		2,260	11,790	187,250	6,600	300	6,900
Pc-16	Trib. Pocono Creek	Monroe Co., Pa.	280	740	430	3,150		1,090	5,690	108,980	3,840	300	4,140
Pc-17	Trib. Pocono Creek	Monroe Co., Pa.	280	740	430	3,150		1,090	5,690	88,740	3,130	300	3,430
Pc-18	Reeders Run	Monroe Co., Pa.	50	320	500	7,660		1,990	10,520	263,500	9,290	300	9,590
Pc-19	Rocky Run	Monroe Co., Pa.	40	220	350	5,260		1,360	7,230	164,190	5,790	300	6,090
Pc-20	Bulgers Run	Monroe Co., Pa.	30	160	240	3,730		960	5,120	134,430	4,740	300	5,040
Pc-21	Cranberry Creek	Monroe Co., Pa.	30	190	300	4,620		1,200	6,340	176,910	6,240	300	6,540
Pc-22	Wigwam Creek	Monroe Co., Pa.	30	190	300	4,620		1,200	6,340	144,930	5,110	300	5,410
WG-1	E. Br. Monocacy Creek	Northampton Co., Pa.	560	5,480	300	1,820	160	2,010	10,330	197,700	6,970	300	7,270
Hz-6	Mauch Chunk Creek	Carbon Co., Pa.	-	8,830	4,700	700		3,560	17,790	468,890	16,530	300	16,830
DG-1	Little Martins Creek	Northampton Co., Pa.	30	3,500	790	200		1,130	5,650	157,200	5,540	300	5,840
WG-5	Bushkill Creek	Northampton Co., Pa.	440	21,720		4,720	400	6,740	34,020	362,770	12,790	300	13,090
Gt-7	Trib. Tacony Creek	Montgomery Co., Pa.			4,600			1,150	5,750	120,290	4,240	300	4,540
Gt-10	Little Neshaminy Creek	Bucks Co., Pa.	480	2,460	5,680	920	80	2,350	11,970	333,600	11,760	300	12,060
Gt-11	Park Creek	Montgomery Co., Pa.	440	2,240	5,160	840	70	2,140	10,890	227,240	8,010	300	8,310
Mt-1	W. Br. Stony Creek	Montgomery Co., Pa.		4,800				1,200	6,000	151,850	5,350	300	5,650
Mt-2	Trib. Stony Creek	Montgomery Co., Pa.		5,410				1,350	6,760	112,970	3,980	300	4,280
Gt-4	Trib. Sandy Run	Montgomery Co., Pa.		1,670	1,160	2,340	640	1,390	7,200	143,880	5,070	300	5,370
Gt-13	Trib. Sandy Run	Montgomery Co., Pa.		900	620	1,250	340	740	3,850	104,280	3,680	300	3,980
Total			17,870	95,490	60,970	296,200	2,950	113,320	586,800	9,626,400	339,380	11,700	351,080

TABLE R-17

RECREATION ELEMENTS OF JIM THORPE, SWIFTWATER AND PARKSIDE RESERVOIR SITES

	Jim Thorpe		Swiftwater		Parkside	
	Design I 1/	Design II	Design I 1/	Design II	Design I 1/	Design II
Recreational Storage 2/						
Elevation (ft. m.s.l.)	952.5	971.0	888.0	910.5	768.0	820.0
Water surface (acres)	14	100	9	50	7	100
Storage capacity (ac.-ft.)	80	1,100	71	650	52	2,050
Flood Control Storage						
Elevation (ft. m.s.l.)	976.0	982.0	942.0	947.0	822.0	837.0
Storage capacity (ac.-ft.)	1,520	1,520	3,279	3,279	2,218	2,218
Spillway						
Crest elevation (ft. m.s.l.)	976.0	982.0	942.0	947.0	822.0	837.0
Crest length (ft.)	50	50	70	70	70	70
Storage at Crest (ac.-ft.)	1,600	2,620	3,350	3,929	2,270	4,268
Dam & Embankment						
Top of dam (ft. m.s.l.)	988.0	994.0	958.0	963.0	835.0	850.0
Height of dam (ft.)	53	59	88	93	80	95
Embankment (cu. yds.)	161,000	255,000	536,000	632,000	434,000	695,700
Cost of Dam						
Total cost (dollars)	469,000	638,000	1,079,000	1,264,000	1,022,000	1,454,200
Unit cost (dollars/cu. yd.)	2.92	2.50	2.01	2.00	2.36	2.09
Recreation Costs						
Real estate (dollars)	800	20,700	300	600	800	18,300
Facilities (dollars)	12,900	148,300	3,600	26,600	9,800	148,300
Increased cost of dam (dollars)	-	169,000	-	185,000	-	432,200
Total recreation cost (dollars)	13,700	338,000	3,900	212,200	10,600	598,800
Annual visitation (persons)	3,800	37,500	1,300	12,500	1,900	37,500
Cost per visitor-day 3/	0.474	0.429	0.76	0.71	0.895	0.672

1/ Based on cost of flood control project with incidental recreational use of sediment pool.
2/ Includes allocation for sediment accumulation.
3/ Includes annual charges.

TABLE R-18
SMALL DAM AND RESERVOIR POTENTIALS

Site	Stream	Drainage Area (sq.mi.)	Maximum Pool Elev. (feet)	Max. Res. Capacity (ac.-ft.)	Surface Area Inundated (acres)
	EAST BRANCH DELAWARE RIVER				
An-1	Berry Brook	3.9	1,750	912	38
An-4	Basin Clove	3.6	1,660	1,049	44
An-5	Falls Clove	10.7	1,480	3,238	162
An-6	Trib. to Downs Brook	1.2	1,820	373	19
An-8	Trib. to E. Br. Del. R.	1.7	1,380	374	16
An-9	Bullet Hole	7.3	1,600	1,993	100
An-10	Trib. to E. Br. Del. R.	2.6	1,660	747	31
Ht-2	Trib. to E. Br. Del. R.	4.7	1,720	2,690	75
Ht-3	Pleasant Valley Brook	4.9	1,640	1,246	62
LM-5	Benton Hollow	4.1	1,675	1,507	69
LM-6	Horse Brook	2.5	1,400	598	25
LE-7	Trout Brook	7.4	1,720	1,644	69
LE-8	Peas Eddy Brook	5.0	1,120	1,133	44
Mg-1	Platte Kill	7.9	1,700	2,088	87
Mg-2	Trib. to Platte Kill	2.0	1,800	497	31
Mg-3	Beaver Kill	6.2	2,440	2,480	62
Mg-4	Red Kill	6.2	1,800	2,241	93
Ne-3	Beaver Kill	3.8	1,900	996	62
Ne-4	Frog Hollow	2.6	1,900	747	31
Wa-1	Dry Brook	2.2	1,560	1,744	44
Wa-6	Baxter Brook	4.7	1,420	3,836	87
Wa-8	W. Trout Brook	3.4	1,560	1,645	38
Wa-11	Morrison Brook	2.2	1,360	1,368	31
Wa-12	East Brook	3.7	1,360	1,569	44
Wa-13	Rich Creek	2.1	1,660	498	25
	WEST BRANCH DELAWARE RIVER				
An-11	Bagley Brook	14.7	1,640	3,487	87
De-2	W. Planter Brook	5.6	1,580	2,267	44
De-3	Dry Brook	2.6	1,800	561	19
De-4	Trib. to Elk Creek	2.9	1,800	997	50
De-5	Trib. to Kidd Creek	2.3	1,900	2,989	62
De-6	Trib. to Wright Brook	2.5	1,780	1,619	31
De-9	E. Planter Brook	6.3	1,580	5,580	100
De-10	Peak Brook	3.5	1,740	2,616	87
De-11	Steele Brook	5.8	1,700	2,466	69
De-12	Falls Creek	6.8	1,700	3,139	88
De-13	Brush Brook	5.3	1,800	5,157	144

TABLE R-18 - Continued
SMALL DAM AND RESERVOIR POTENTIALS

Site	Stream	Drainage Area (sq.mi.)	Maximum Pool Elev. (feet)	Max. Res. Capacity (ac.-ft.)	Surface Area Inundated (acres)
	WEST BRANCH DELAWARE RIVER - Continued				
De-14	Trib. to L. Del. R.	2.0	1,820	1,134	44
De-16	Trib. to L. Del. R.	3.4	1,640	1,794	75
De-17	Trib. to Del. R.	1.2	1,600	349	13
De-18	Trib. to L. Del. R.	1.2	1,720	1,121	31
Dp-1	Starboard Cr.	2.4	1,460	3,585	100
Dp-2	Bullark Creek	1.7	1,460	1,245	31
Dp-3	Sherruck Brook	3.2	1,520	1,370	69
Dp-4	Steam Mill Brook	3.6	1,500	1,794	56
Dp-5	Trib. to Cold Spring Cr.	2.6	1,460	2,242	56
Dp-6	Trib. to Oquaga Cr.	3.4	1,540	2,913	81
Dp-8	Dry Brook	3.7	1,440	3,885	75
Dp-10	Dry & Barbour Brooks	4.4	1,240	1,395	50
Dp-13	Tarbell Brook	2.5	1,300	1,120	31
Dp-15	Laurel Creek	2.3	1,380	3,559	81
Dp-16	Road Creek	4.1	1,220	2,741	62
Dp-17	Whitaker Brook	1.2	1,200	1,120	31
Dp-18	Dry Brook	1.9	1,400	1,346	37
Dp-19	Trib. to W. Br. Del. R.	2.0	1,200	1,245	31
Nh-1	Trib. to Marsh Cr.	1.2	1,500	997	50
Ht-1	Trib. to W. Br. Del. R.	1.6	1,640	1,121	32
Ht-4	Rose Brook	7.5	1,860	5,232	131
St-9	Trib. to Shehawken	1.5	1,600	997	62
St-10	Trib. to Shehawken	1.3	1,500	555	69
St-11	Star Creek	2.4	1,260	1,495	31
St-14	Sherman Cr.	2.3	1,400	1,246	31
Wa-3	Johnnie Brook	2.3	1,380	2,741	63
Wa-4	Fish Brook	2.0	1,500	1,245	31
Wa-5	Chase Brook	2.4	1,660	2,464	56
	HANCOCK TO PORT JERVIS				
Ar-1	Trib. to Wallenpaupack	6.9	1,320	4,800	200
Ar-2	Butternut Cr.	10.0	1,320	2,790	87
Da-2	Carley Brook	4.7	1,280	1,395	87
Da-3	Rattlesnake Cr.	29.2	920	6,377	199
Da-4	Trib. to Del. R.	4.0	860	897	38
Da-5	Calkins Cr.	15.9	980	3,587	150
Da-7	Beaverdam Cr.	1.7	920	3,020	108
Da-8	Carley Brook	12.5	1,080	2,080	130

TABLE R-18 - Continued
SMALL DAM AND RESERVOIR POTENTIALS

Site	Stream	Drainage Area (sq.mi.)	Maximum Pool Elev. (feet)	Max. Res. Capacity (ac.-ft.)	Surface Area Inundated (acres)
	HANCOCK TO PORT JERVIS - Continued				
Da-10	S. Br. Calkins Cr.	16.7	880	4,484	187
Da-14	Trib. S. Br. Calkins Cr.	2.7	1,240	598	38
Da-16	Trib. to Lackawaxen R.	8.0	1,040	1,794	56
En-1	Primrose Cr.	5.1	1,200	1,593	50
Ha-1	Mudpond Run	6.3	1,300	2,988	124
Ha-2	Brights Cr.	4.3	1,380	1,868	78
Ha-3	Shohola Cr.	11.7	1,380	5,976	498
Ha-4	Gates Run	2.7	1,460	996	62
Ha-5	Burchards Cr.	2.2	1,200	640	40
Ha-6	Swamp Brook	7.9	1,080	7.360	230
Ha-7	Wangum Cr.	8.9	720	5,565	236
Ha-8	E. Br. Paupack Cr.	14.4	1,720	3,584	448
Hd-2	Middle Cr.	22.3	1,200	1,650	275
Hd-3	Trib. to Middle Cr.	3.4	1,260	2,541	106
Hd-4	E. Br. Dyberry Cr.	11.6	1,100	4,185	175
Hd-5	Trib. to Lackawaxen R.	11.7	1,300	2,190	274
Hd-6	Trib. to Middle Cr.	9.7	1,340	6,120	306
Hd-7	Collins Brook	5.3	1,260	1,824	114
LM-1	North Branch	6.9	1,130	1,869	62
LM-3	Trib. to E. Br. Callicoon	2.8	1,360	685	25
LM-4	Panther Rock Br.	6.0	1,275	1,699	62
LE-1	Hollishan Bk.	2.4	1,420	523	44
LE-2	Pea Brook	2.1	1,165	822	37
LE-3	Brouchoux Brook	3.4	1,060	747	31
LE-4	Abe Lord Cr.	4.7	1,120	1,495	62
LE-5	Basket Cr. E. Br.	9.2	1,380	2,267	81
LE-6	Hollister Cr.	8.1	1,010	1,744	62
LE-10	Tyler Brook	3.6	1,000	872	44
Mf-4	Cabin Cr.	3.6	700	1,244	31
Mf-5	Mill Brook	16.3	880	5,230	93
Mt-1	Sheldrake	7.4	1,300	2,490	125
Mt-2	Fowlwood Brook	8.0	1,280	1,744	44
Mt-3	South Brook	2.4	1,280	1,494	47
Mt-4	Spring Brook	2.2	1,280	796	50
Ne-1	Neversink R.	4.8	1,280	1,792	112
Ne-2	Trout Brook	1.7	1,480	747	37
Ne-6	Fall Brook	5.3	1,900	2,160	56
Ne-7	Black Joe Brook	2.3	1,760	492	21
Ne-8	Monoquap R.	2.2	1,440	934	47

TABLE R-18 - Continued
SMALL DAM AND RESERVOIR POTENTIALS

Site	Stream	Drainage Area (sq.mi.)	Maximum Pool Elev. (feet)	Max. Res. Capacity (ac.-ft.)	Surface Area Inundated (acres)
	HANCOCK TO PORT JERVIS - Continued				
PJ-1	Trib. to Neversink R.	2.6	580	992	62
PJ-2	Trib. to Neversink R.	3.9	720	1,245	31
PJ-4	Trib. to Delaware R.	2.0	600	1,245	31
St-1	Crooked Cr.	8.0	1,200	3,737	156
St-2	Riley Cr.	5.6	1,460	5,381	168
St-3	Kinneyville	11.0	1,280	5,729	143
St-4	Factory Cr.	3.2	1,300	3,986	127
St-5	Trib. Delaware R.	1.9	1,200	747	31
St-13	Johnson Cr.	4.3	1,700	1,196	75
St-16	Unknown	1.6	1,400	2,989	93
SM-1	E. Br. Neversink Cr.	6.6	2,360	1,793	75
WL-2	Beaver Brook	17.4	1,040	7,100	355
	PORT JERVIS TO BELVIDERE				
Bu-2	Goose Pond Run	7.0	1,260	10,100	153
Bu-3	Spruce Cabin Run	2.3	1,180	670	56
Bu-4	Stony Mud Run	9.2	970	5,150	134
Bu-8	Michaels Cr.	3.3	860	420	15
Bu-9	Butz Run	3.0	840	1,980	45
Bu-12	Trib. to Marshall	1.7	800	498	25
Bu-13	Trib. to Saw Cr.	4.1	1,240	1,133	81
Bu-14	Trib. to Bushkill Cr.	1.2	1,000	598	37
Bu-15	Saw Creek	6.9	800	3,114	104
DG-2	Trib. to Cherry Cr.	1.8	860	3,737	156
DG-3	Stony Brook	3.9	560	3,487	176
Hk-2	Bear Creek	5.5	540	1,750	220
Hk-3	Trout Brook	2.9	560	1,800	230
Hk-4	Bear Creek	6.7	560	7,464	622
Mf-1	Dwarfs Kill	7.0	1,080	1,990	62
Mf-2	Saw Kill	8.7	1,080	2,488	62
Mf-3	Cunnings Cr.	3.6	1,040	2,490	62
Pc-3	Brodhead Cr.	1.2	1,640	2,490	62
Pc-4	Buck Hill Cr.	4.2	1,800	36,200	313
Wp-1	Trib. to Paulins Kill	3.1	680	3,562	81
Wp-2	Big Flat Brook	2.6	820	1,370	50
Wp-3	Trib. to Paulins Kill	2.6	580	1,868	93
Wp-4	Trib. to Paulins Kill	1.5	500	598	25
Wp-5	Tom Cr.	3.9	1,020	1,619	81

TABLE R-18 - Continued
SMALL DAM AND RESERVOIR POTENTIALS

Site	Stream	Drainage Area (sq.mi.)	Maximum Pool Elev. (feet)	Max. Res. Capacity (ac.-ft.)	Surface Area Inundated (acres)
	PORT JERVIS TO BELVIDERE - Continued				
Wp-6	Trib. to Delaware R.	4.2	740	2,466	69
Wp-7	Hoynbecks Cr.	9.5	640	4,110	69
	BELVIDERE TO TRENTON				
Dy-1	Lackatong	19.4	400	9,964	249
Dy-2	Trib. to Tohickon Cr.	1.5	400	544	18
Dy-4	Deep Run	2.3	520	606	43
Ea-1	Hankokake Cr.	9.2	220	4,534	162
Ea-2	Gallows Run	3.4	300	1,744	62
Ea-3	Trib. Hankokake Cr.	2.8	520	897	37
Hk-1	Trib. to Pohatcong Cr.	1.2	869	593	44
Qu-11	Three Mile Run	5.8	403	1,980	135
La-1	Wicheoeheoke Cr.	20.0	320	8,960	249
	TRENTON TO PHILADELPHIA				
Gt-1	Ironworks Cr.	1.6	300	1,395	87
Gt-3	Trib. Wissahickon Cr.	6.5	130	496	62
Gt-8	Trib. Pennypack Cr.	2.8	120	997	62
Gt-15	Trib. to Neshaminy Cr.	4.3	220	1,221	87
Gt-16	Trib. to Neshaminy Cr.	2.7	220	630	48
MH-1	Trib. to Rancocas Cr.	3.6	30	9,341	94
Dy-5	N. Br. Neshaminy Cr.	16.8	305	5,789	361
	LEHIGH RIVER				
AW-1	Hassen Cr.	7.0	420	2,390	99
Hz-1	Beaver Brook	7.6	1,560	3,220	201
Hz-2	Quakake Cr.	6.7	1,240	2,410	177
Hz-3	Hazle Cr.	15.2	1,380	4,970	276
Hz-5	Trib. to Nesquehoning Cr.	6.0	1,800	5,978	249
MC-1	Aquashicola Cr.	1.5	800	920	46
MC-2	Pine-Whiteoak Run	4.8	860	2,840	12
MC-3	Bear Creek	4.5	1,300	1,196	50
MC-4	Trib. Pine Whiteoak Run	1.3	1,000	399	25
Sd-1	Hickory Sand Spring Run	10.0	1,160	2,018	56
Sd-2	Shades Cr.	9.2	1,520	3,139	87
Sd-3	Bear Cr.	12.0	1,780	4,110	206

TABLE R-18 - Continued
SMALL DAM AND RESERVOIR POTENTIALS

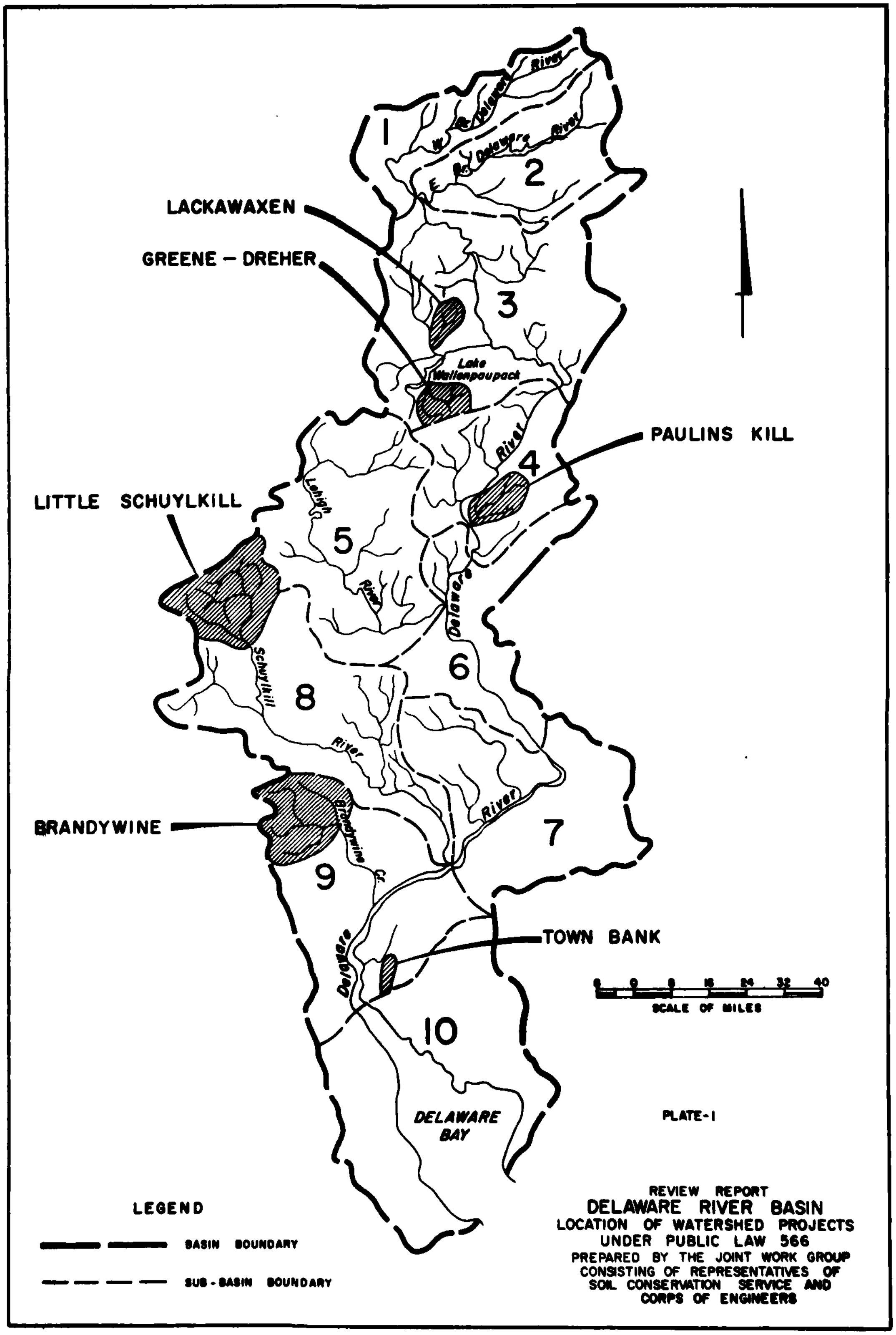
Site	Stream	Drainage Area (sq.mi.)	Maximum Pool Elev. (feet)	Max. Res. Capacity (ac.-ft.)	Surface Area Inundated (acres)
	LEHIGH RIVER - Continued				
Sd-4	Dilldown Cr.	5.3	1,570	1,495	125
WG-2	Aquashicola Cr.	4.8	660	5,230	262
WG-3	Aquashicola Cr.	19.8	560	2,020	560
WG-4	Hokendauqa Cr.	9.5	660	2,490	155
	SCHUYLKILL RIVER				
By-1	Pine Creek	1.3	800	598	37
By-2	Trib. Perkiomen Cr.	2.4	440	1,030	68
By-3	Manatawney Cr.	7.5	410	3,970	248
By-4	Perkiomen Cr.	4.1	580	2,120	102
By-5	Hosensack Cr.	18.0	390	3,900	207
By-6	Trib. Schuylkill R.	1.7	159	883	54
By-7	Trib. Manatawney Cr.	2.4	213	862	46
By-8	Sacony Cr.	2.45	840	1,355	68
By-9	Ministers Cr.	5.7	280	1,670	167
By-10	Trib. Manatawney Cr.	1.4	208	1,389	67
By-11	Trib. Manatawney Cr.	1.6	240	538	50
By-13	Perkiomen Cr.	10.2	620	3,000	175
By-14	Trib. Perkiomen Cr.	2.0	320	475	48
Hg-1	Kistler Cr.	9.5	440	2,310	152
Hg-4	Pine Cr.	11.0	460	4,280	262
Hg-5	Trib. Ontelawnee Cr.	3.7	450	864	108
Hb-1	Sixpenny Cr.	1.3	540	2,493	92
Hb-9	Hay Cr.	12.6	360	2,910	260
Hb-10	French Cr.	11.7	460	2,800	212
Hb-11	Allegheny Cr.	10.0	360	3,100	194
Ln-1	Tulpehocken Cr.	13.0	500	4,360	545
Ln-2	Trib. Tulpehocken Cr.	10.6	490	2,640	330
Mt-3	Skippack Cr.	33.5	187	7,128	405
PG-1	W. Br. Schuylkill R.	4.8	1,250	1,540	80
Px-1	S. Br. French Creek	12.5	400	7,960	276
Px-2	Pigeon Cr.	11.7	200	4,840	242
Pt-2	Stony Cr.	3.2	660	2,294	48
Pt-3	Trib. Schuylkill R.	16.8	420	8,000	400
Pt-4	Plum Cr.	4.9	520	2,430	152
Pt-6	Trib. Schuylkill R.	6.4	560	3,010	188
QU-1	Trib. Perkiomen Cr.	1.2	220	250	16
QU-2	Haselbach Cr.	1.5	480	867	54

TABLE R-18 - Continued
SMALL DAM AND RESERVOIR POTENTIALS

Site	Stream	Drainage Area (sq.mi.)	Maximum Pool Elev. (feet)	Max. Res. Capacity (ac.-ft.)	Surface Area Inundated (acres)
	SCHUYLKILL RIVER - Continued				
QU-3	Trib. Hosensack Cr.	1.4	500	2,004	72
QU-4	E. Br. Perkiomen Cr.	1.0	200	471	31
QU-5	Trib. Perkiomen Cr.	3.4	200	883	52
QU-6	Hosensack Cr.	3.0	540	2,690	125
QU-7	Butter Cr.	2.5	480	1,992	127
QU-8	Ridge Valley Cr.	6.6	400	6,020	430
QU-9	Skippack Cr.	6.4	230	2,340	195
QU-10	Trib. Mill Cr.	1.1	380	279	24
QU-12	Unami Cr.	6.6	520	1,360	113
QU-13	Indian Cr.	5.8	260	3,920	218
QU-15	Unami Cr.	35.8	320	9,964	311
Re-4	Furnace Cr.	2.0	660	897	37
Re-5	L. Manatawney Cr.	1.9	580	530	28
We-1	Molleads Cr.	22.0	340	4,800	300
We-2	Irish Cr.	12.3	360	2,600	260
We-3	Spring Cr.	11.5	365	2,460	176
We-4	Mountain Cr.	6.2	360	2,340	146
We-5	Cacoosing Cr.	15.6	295	3,740	311
We-7	Trib. Spring Cr.	5.0	320	1,868	78
We-8	Furnace Cr.	4.0	640	2,242	57
	PHILADELPHIA TO BAY				
Cr-3	Trout Run	2.7	200	2,092	87
Cr-6	Trib. Ridley Cr.	1.3	200	1,196	37
Ct-3	Doe Run	1.4	520	647	81
Ct-4	Trib. Brandywine Cr.	2.0	320	1,620	81
Ct-5	Buck Run	24.9	320	5,370	274
Ct-7	Middle Bk. White Clay	7.9	360	2,430	135
Ct-8	Sucker Run	1.5			
Hb-7	Trib. Brandywine Cr.	3.9	620	4,336	81
Hb-7	Trib. Brandywine Cr.	1.4	580	8,220	206
WC-1	Broad Run	1.2	400	1,150	75
WC-2	Trib. Brandywine Cr.	1.0	340	2,242	93
WC-3	Trib. Brandywine Cr.	2.6	360	2,929	199
WC-4	Chester Cr.	2.3	320	721	75
WC-5	Trib. Red Clay Cr.	1.9	300	1,256	62
WC-7	Trib. Brandywine Cr.	1.1	300	1,594	50
WC-8	Trib. White Clay Cr.	6.2	240	7,536	314

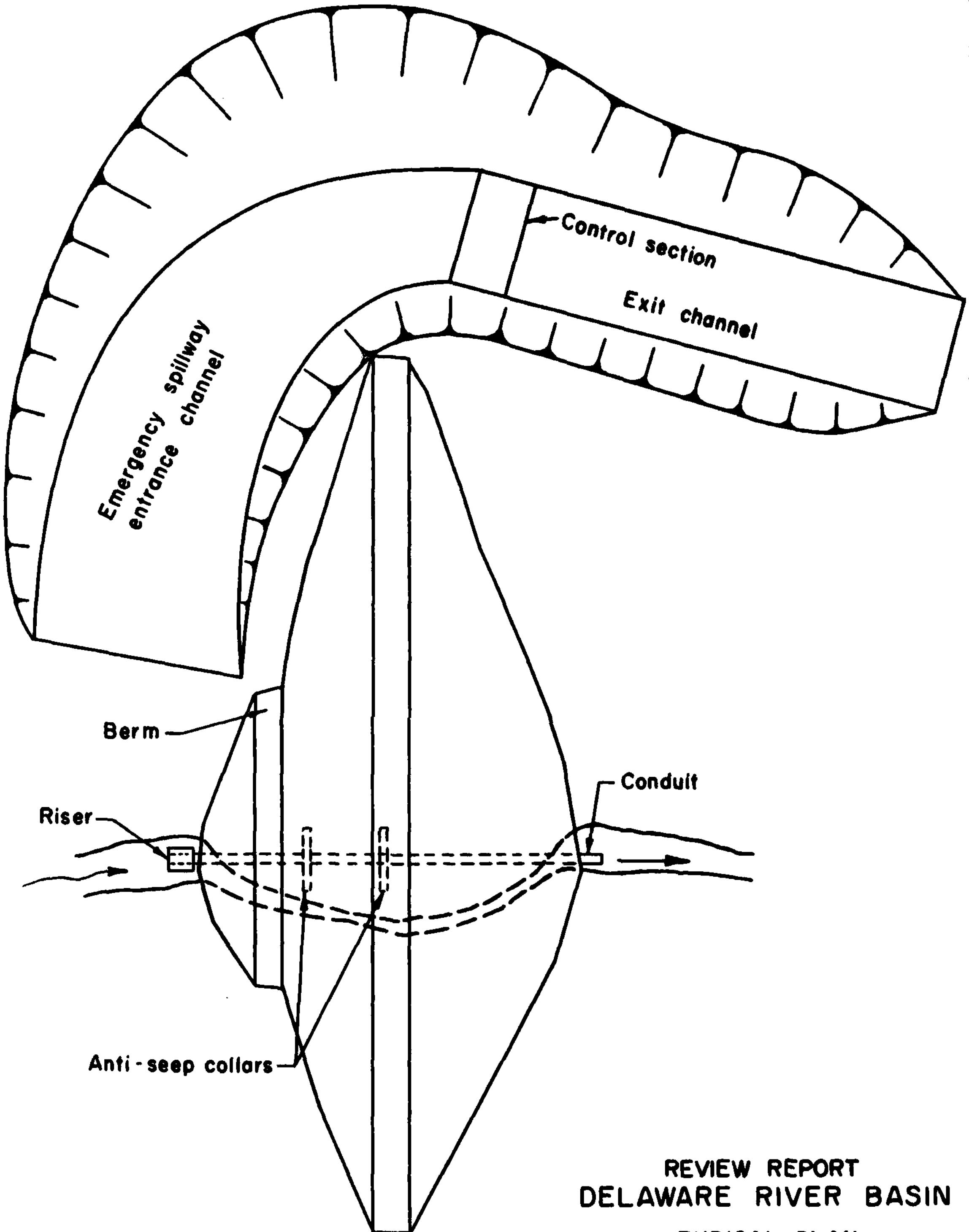
TABLE R-18 - Continued
SMALL DAM AND RESERVOIR POTENTIALS

Site	Stream	Drainage Area (sq.mi.)	Maximum Pool Elev. (feet)	Max. Res. Capacity (ac.-ft.)	Surface Area Inundated (acres)
	PHILADELPHIA TO BAY - Continued				
WC-9	Ring Run	1.4	270	299	25
Px-9	Marsh Run	15.7			
Wt-1	Trib. White Clay Cr.	3.4	170	7,869	249
Wt-2	Trib. White Clay Cr.	4.8	170	5,956	219
Ek-1	Christina R.	6.2	200	3,490	174



W. Br. Delaware River
E. Br. Delaware River
1
2
3
4
5
6
7
8
9
10
LACKAWAXEN
GREENE – DREHER
Lake Wallenpaupack
PAULINS KILL
LITTLE SCHUYLKILL
Lehigh River
Delaware River
Schuylkill River
BRANDYWINE
Brandywine Cr.
TOWN BANK
Delaware
DELAWARE BAY
0 8 16 24 32 40
SCALE OF MILES
PLATE-I
LEGEND
BASIN BOUNDARY
SUB-BASIN BOUNDARY
REVIEW REPORT
DELAWARE RIVER BASIN
LOCATION OF WATERSHED PROJECTS
UNDER PUBLIC LAW 566
PREPARED BY THE JOINT WORK GROUP
CONSISTING OF REPRESENTATIVES OF
SOIL CONSERVATION SERVICE AND
CORPS OF ENGINEERS

PLATE 1

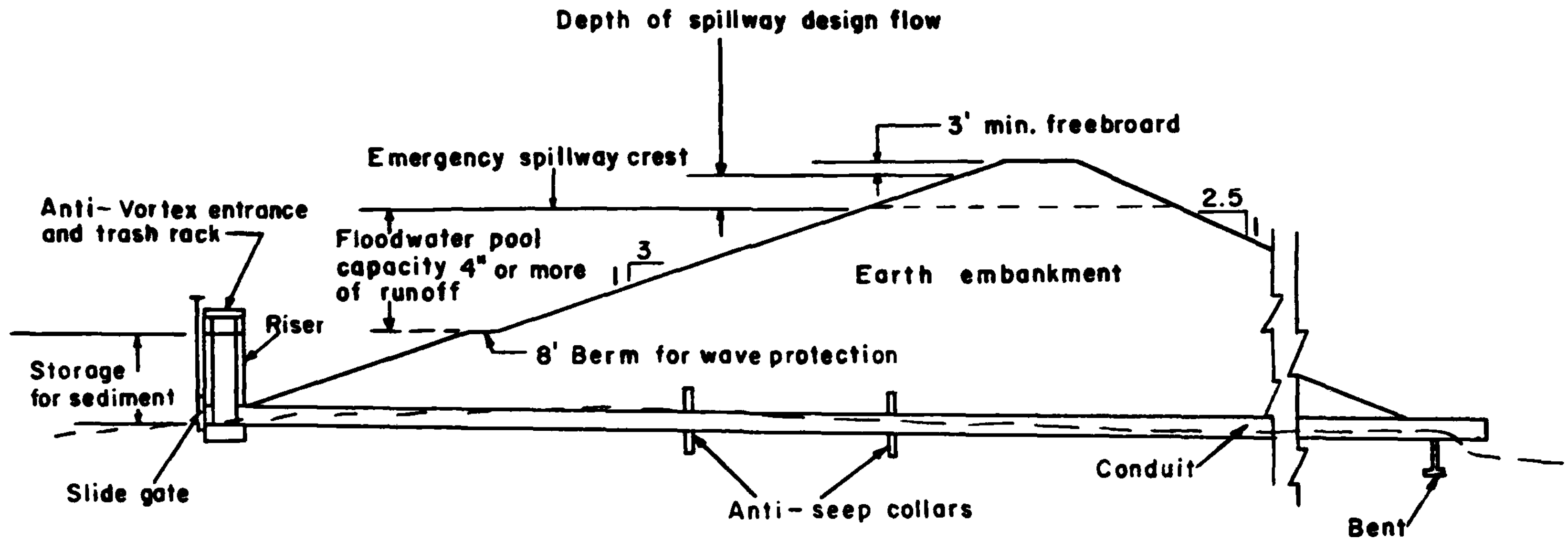


REVIEW REPORT
DELAWARE RIVER BASIN

TYPICAL PLAN
OF A SMALL DAM

PREPARED BY THE JOINT WORK GROUP
SOIL CONSERVATION SERVICE AND
CORPS OF ENGINEERS

PLATE 2



REVIEW REPORT
DELAWARE RIVER BASIN

TYPICAL SECTION OF A
SMALL DAM

PREPARED BY THE JOINT WORK GROUP
SOIL CONSERVATION SERVICE AND
CORPS OF ENGINEERS

PLATE 3

DATA SHEET
DELAWARE RIVER BASIN SURVEY
Reconnaissance of Headwater Dam and Reservoir Sites

Stream	Index Nr.	Name
West Brook (Trib. to W. Br.)	Wa 16	

LOCATION

Map: Walton, N. Y. (1:62,500)	Coordinates: 75° 07' 30" W 42° 11' 30" N
Nearest Town: Walton, N. Y.	Highway: 1 1/2 mi. N of Route 10

WATERSHED

Sq. Mi.	Acre ft. @ 4"
21.5	4594

VALLEY DOWNSTREAM FROM DAM SITE

	Date of Field Recons.: 8-21-58	By: A. Sabin
Length Studied: One Mile	Communities: Walton, N. Y.	
Railroad: None (Abandoned)	Highways: Routes 10 and 206	Bridges: Several in Walton

Potential damage areas: Town of Walton

Stream gradient estimated at 2%

DAM SITE

	Date of Field Recons.: 8-21-58	By: A. Sabin
Bankful Str. width: 20'	Bankful Str. depth: 3'	
Valley width @ W.S.: 800'	Spillway Site: On right abutment	
Rt. Abut.: Steep and rock outcropping	Lt. Abut.: Steep and rock outcropping	

Comments: Rt. bank better location for spillway because of broad bench from abandoned railroad right-of-way. Fill material probably available from broad flood plain.

RESERVOIR

	Date of Field Recons.: 8-21-58	By: A. Sabin
El. W.S.: 1310	Depth @ Dam: 70'	Length: 1.7 mile
Acres: 168	A.F. (SA x 0.4D): 4704	Roads: .5 mi. dirt and paved roads
Limiting Pt.:	Land Use: 85% farmland	
Farm bldg.:	Other Impv.:	

Comments: N.Y. O. & W. R.R. has been abandoned.

COMMENTS, REFERENCES & EVALUATION

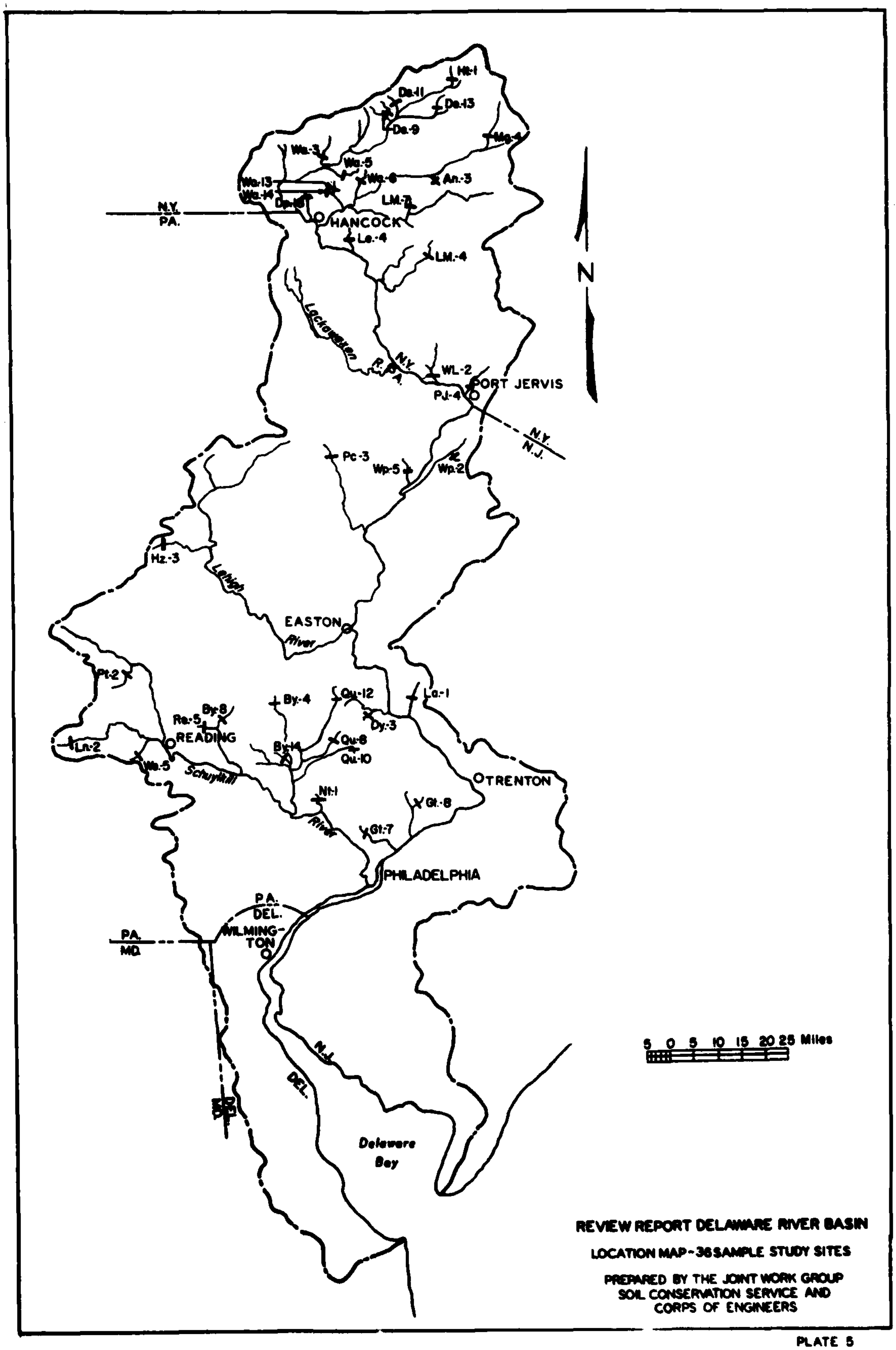
Easement Problems: 75 acres farmland (1/3 in cropland), 1/8 mile black top road, 1/4 mile dirt road (farm lane), 2 houses $8,000 and $10,000, 1 barn and shed, 1 concrete bridge (30' long), 1 mile of powerline.

Damage Reach: 1 1/2 miles from dam site to Delaware St. in Walton.

Flood Damages: Based on flood magnitude of 1935
1 large recreation field and grandstand, 1 swimming pool, 1 concession bldg., 1 small iron bridge, 75 homes (w. basements) in Walton on Liberty St., several bridges damaged and 1 washed out in 1935.

Date Completed	Completed By	Name	Index Nr.
			Wa 16

NADP FORM 1 MAR 57 786 (5-61)



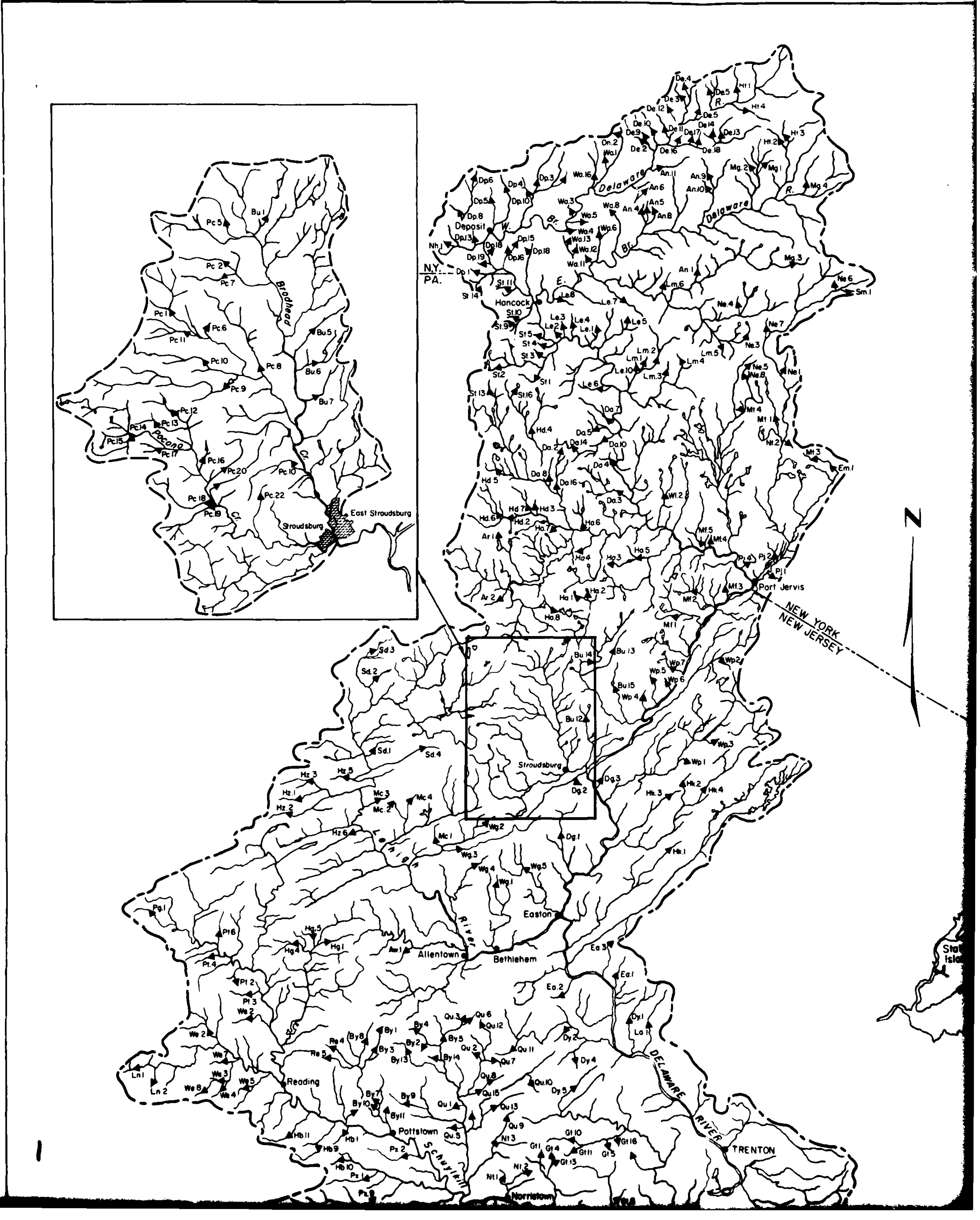
REVIEW REPORT DELAWARE RIVER BASIN

LOCATION MAP - 36 SAMPLE STUDY SITES

PREPARED BY THE JOINT WORK GROUP
SOIL CONSERVATION SERVICE AND
CORPS OF ENGINEERS

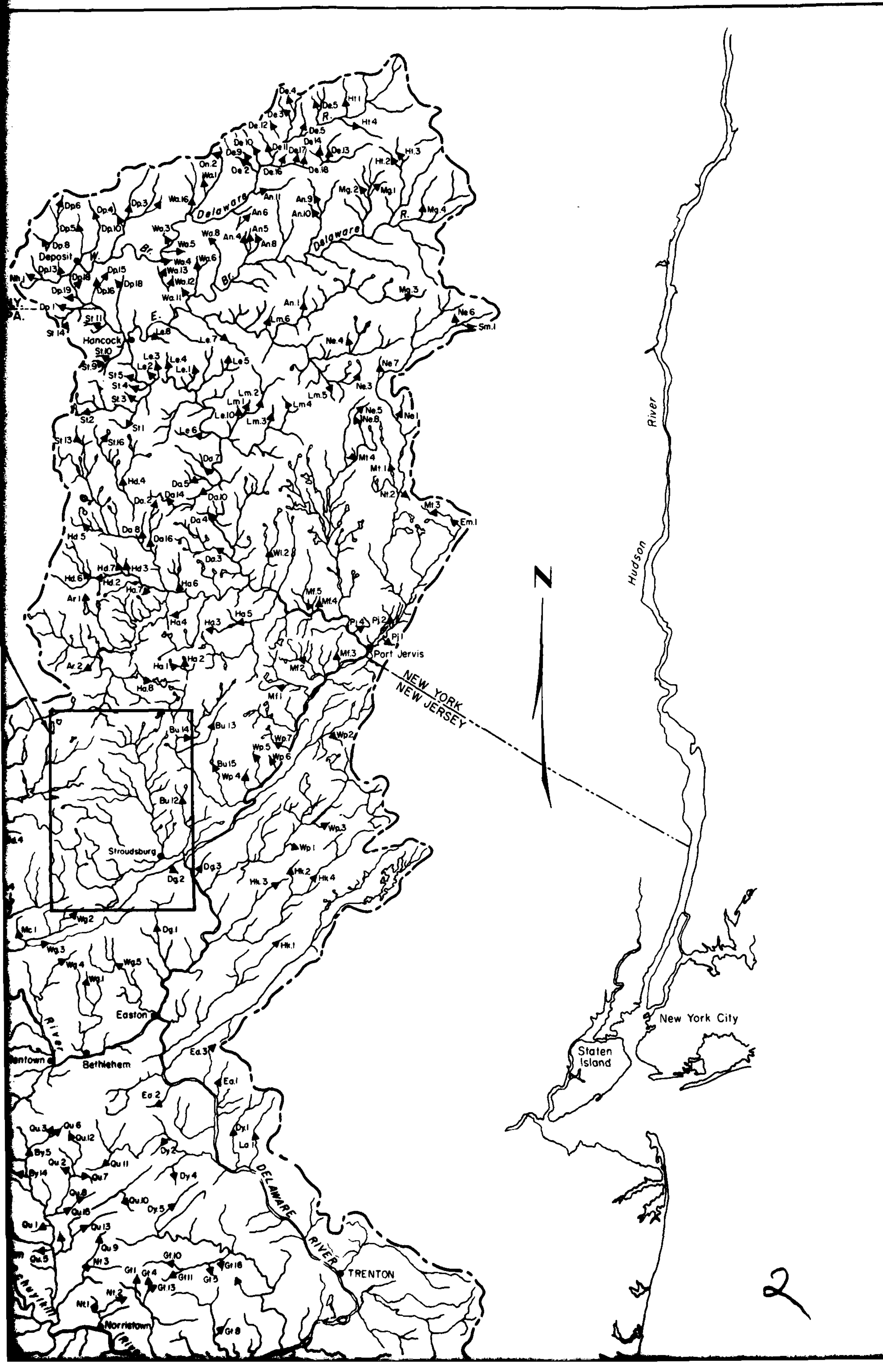
PLATE 5

CORPS OF ENGINEERS



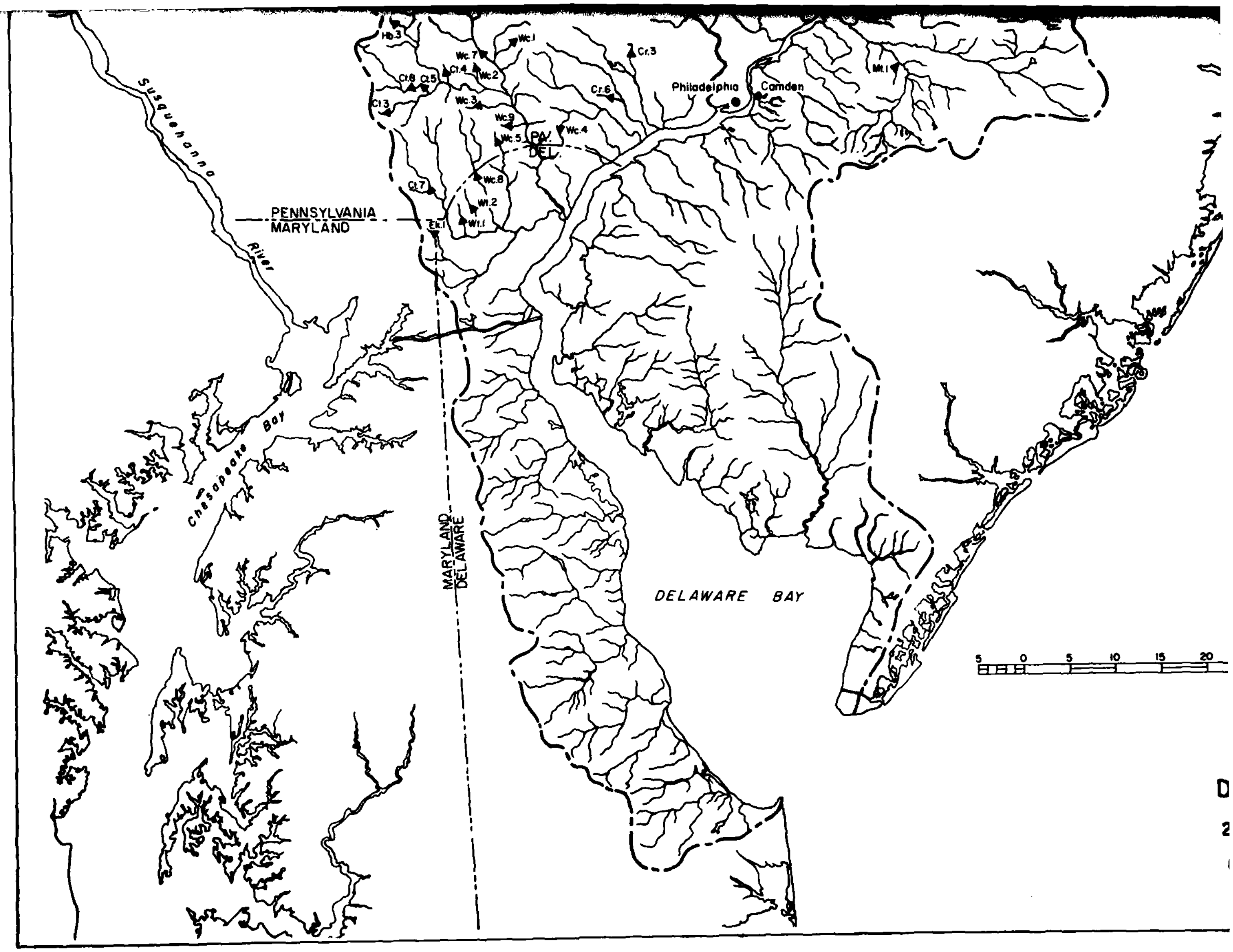
1

U.S. ARMY

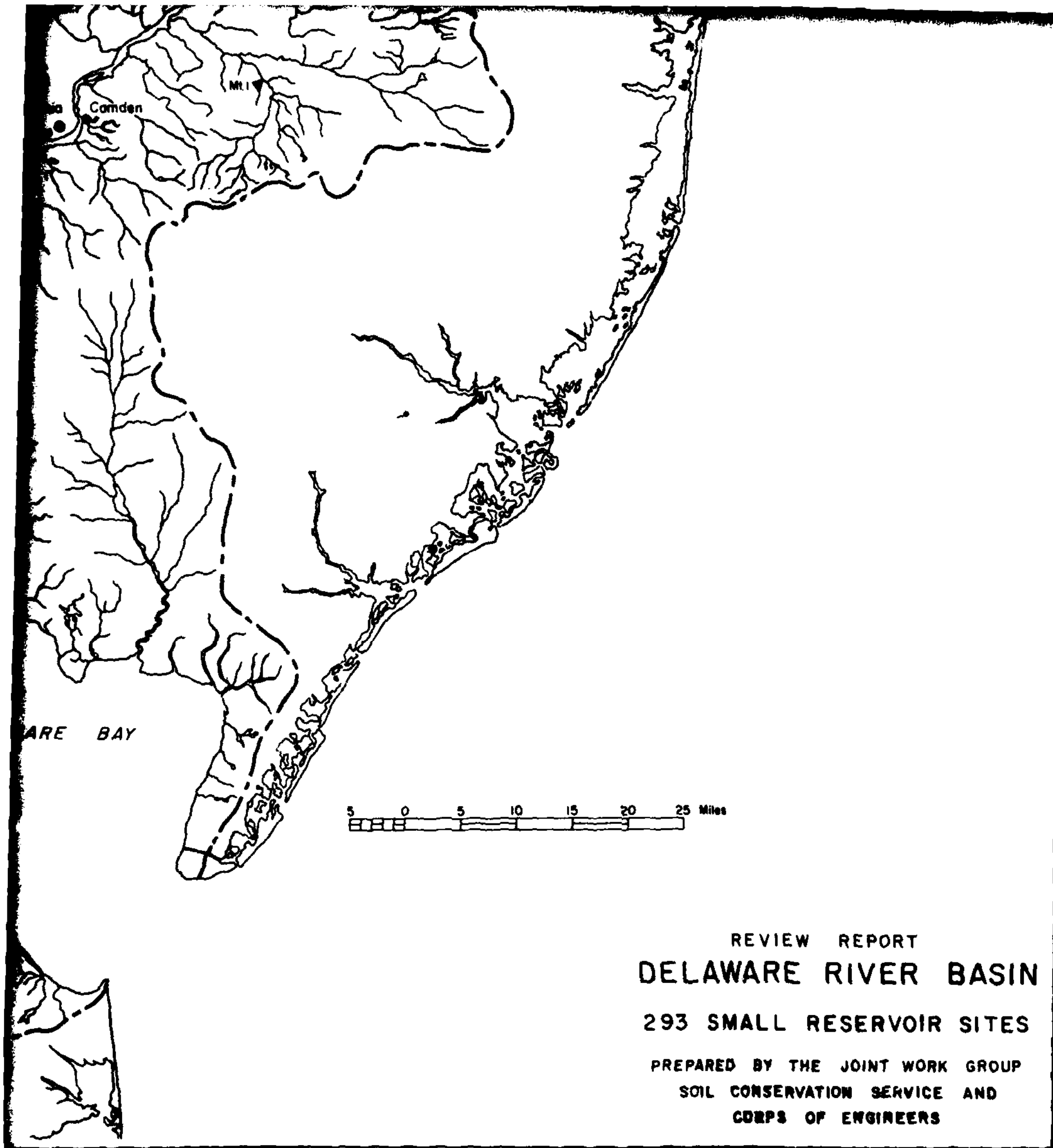


Delaware
W. Br.
E. Br.
Delaware R.
Deposit
Hancock
Port Jervis
NEW YORK
NEW JERSEY
Stroudsburg
Easton
Bethlehem
River
DELAWARE RIVER
TRENTON
Norristown
Hudson River
New York City
Staten Island
N

2


Hb.3
Wc.7
Wc.1
Cr.3
Ct.4
Wc.2
Ct.6
Ct.5
Mt.1
Philadelphia
Camden
Cr.6
Ct.3
Wc.3
Wc.9
Wc.5
PA.
DEL.
Wc.4
Wc.8
Ct.7
Wt.2
PENNSYLVANIA
MARYLAND
Ek.1
Wt.1
Susquehanna
River
Chesapeake Bay
MARYLAND
DELAWARE
DELAWARE BAY
5 0 5 10 15 20

3



REVIEW REPORT

DELAWARE RIVER BASIN

293 SMALL RESERVOIR SITES

PREPARED BY THE JOINT WORK GROUP
SOIL CONSERVATION SERVICE AND
CORPS OF ENGINEERS

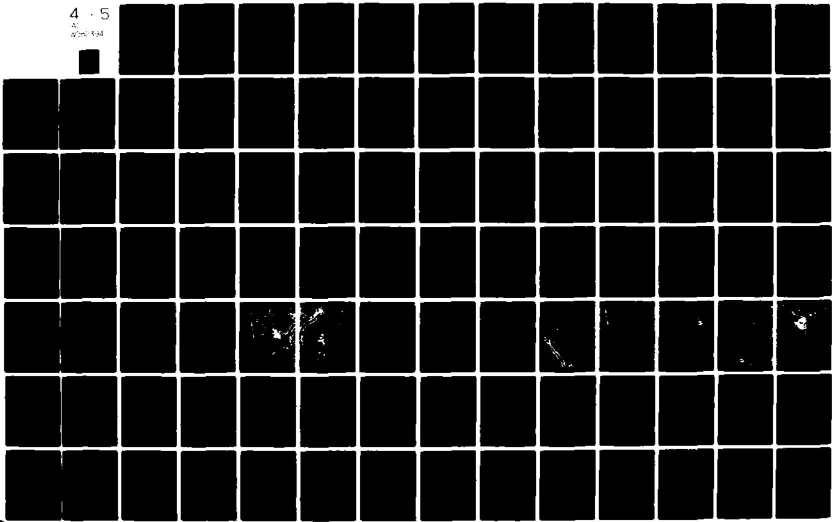
PLATE 6

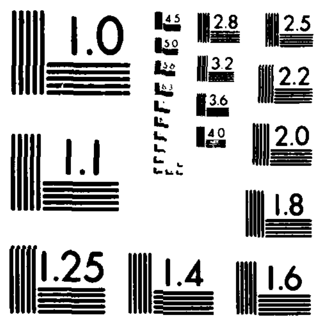
4

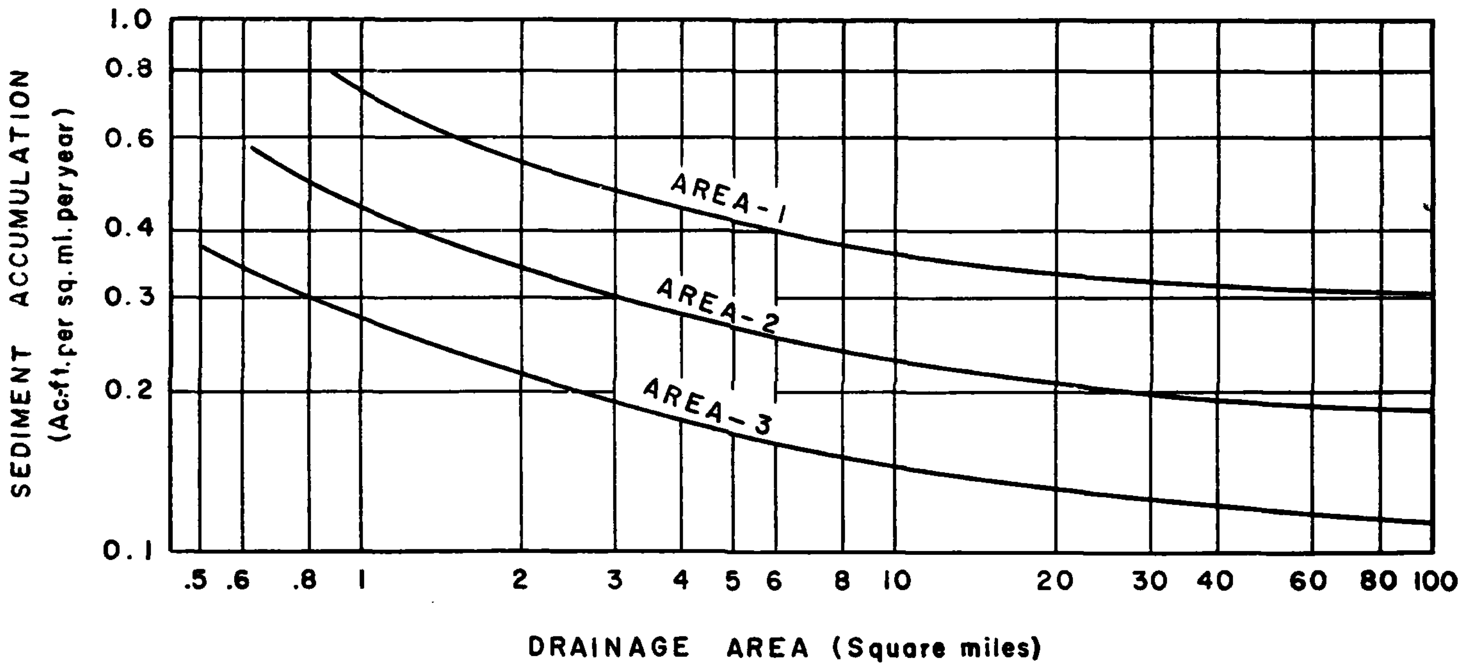
AD-A082 394 ARMY ENGINEER DISTRICT PHILADELPHIA PA F/G 13/2
REPORT ON THE COMPREHENSIVE SURVEY OF THE WATER RESOURCES OF TH--ETC(U)
DEC 60

UNCLASSIFIED NL

4 · 5




1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0
5.6
6.3



CURVE 1– Developed from 10 records in the Triassic basin and the northern Piedmont Plateau.

CURVE 2– Based on 22 records in the southern New England Upland, the glaciated Appalachian valleys and ridges, and the Allentown Valley.

CURVE 3– Based on 19 records in the glaciated shale and sandstone area.

REVIEW REPORT

DELAWARE RIVER BASIN

GENERALIZED CURVES OF RESERVOIR SEDIMENTATION

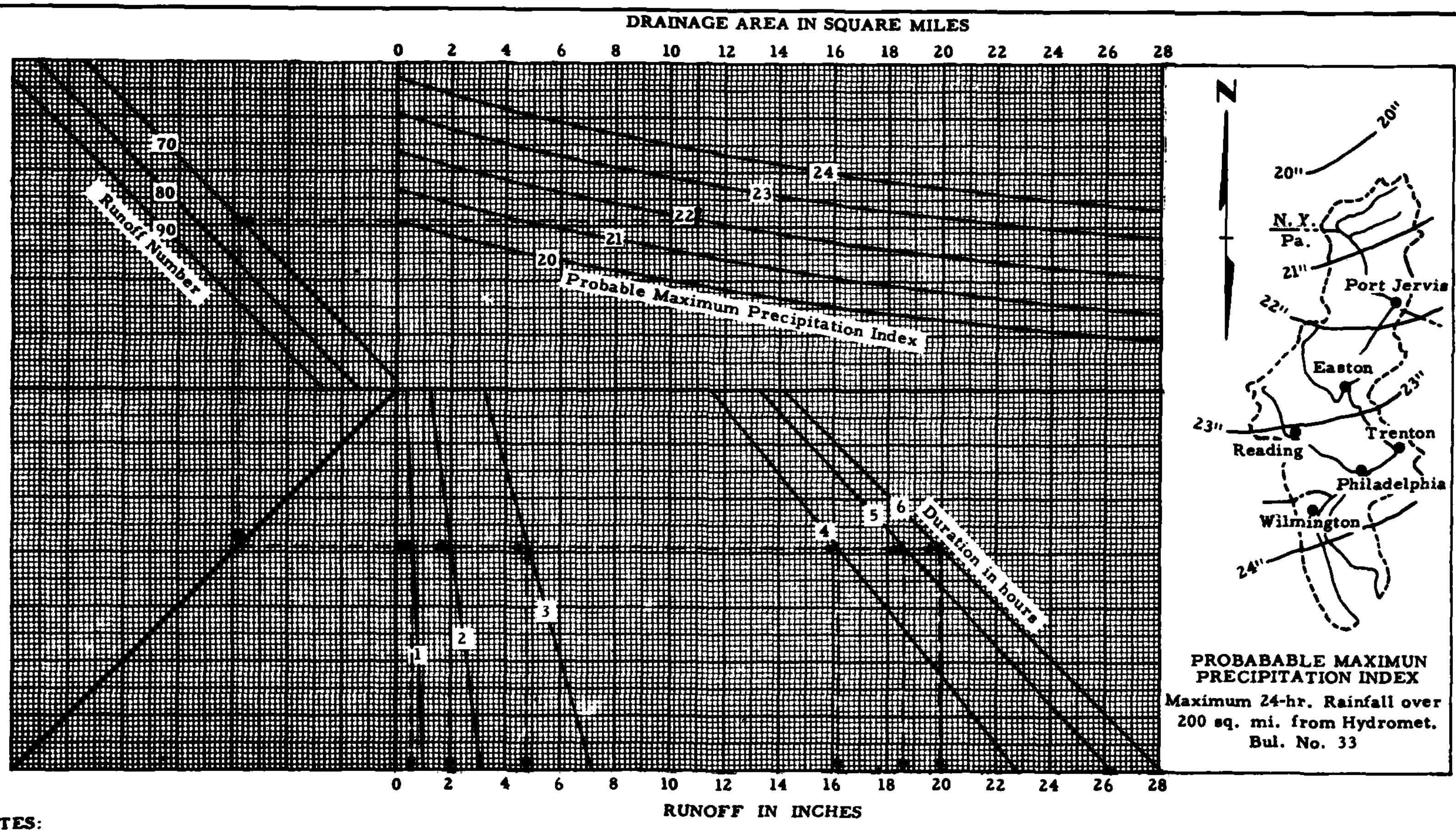
PREPARED BY THE JOINT WORK GROUP SOIL CONSERVATION SERVICE AND CORPS OF ENGINEERS

REVIEW REPORT
DELAWARE RIVER BASIN

AREAS OF SIMILAR
RESERVOIR SEDIMENTATION

PREPARED BY THE JOINT WORK GROUP
SOIL CONSERVATION SERVICE AND
CORPS OF ENGINEERS

PLATE 8



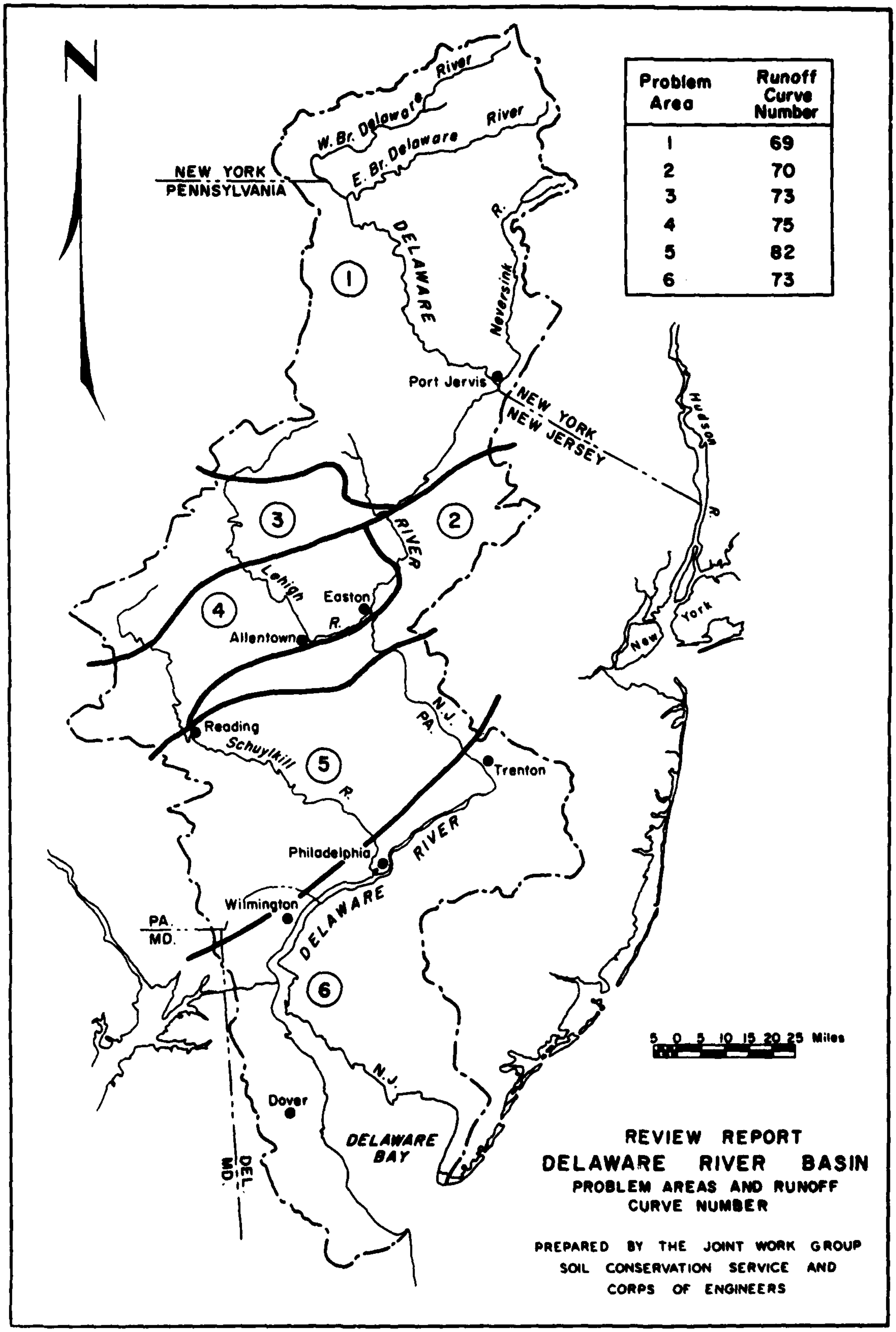
NOTES:

1. This chart used for determination of hourly runoff resulting from probable maximum 6-hr. precipitation.
2. " *Probable maximum precipitation* " determined by Weather Bureau, Hydromet. Bul. No. 33.
3. Loss rates based on hydrologic soil complex and type II antecedent moisture condition, S.C.S. Hydrology Manual.
4. Method-
   a. Locate watershed area on small map and estimate probable maximum precipitation index.
   b. Estimate runoff number from Plate 10.
   c. Using drainage area, maximum precipitation index and runoff number proceed thru the chart as shown by dashed lines.
   d. Accumulated runoff in inches results.

REVIEW REPORT DELAWARE RIVER BASIN

SPILLWAY DESIGN STORM PRECIPITATION AND RUNOFF FOR SMALL RES. PROJECTS

PREPARED BY THE JOINT WORK GROUP SOIL CONSERVATION SERVICE AND CORPS OF ENGINEERS

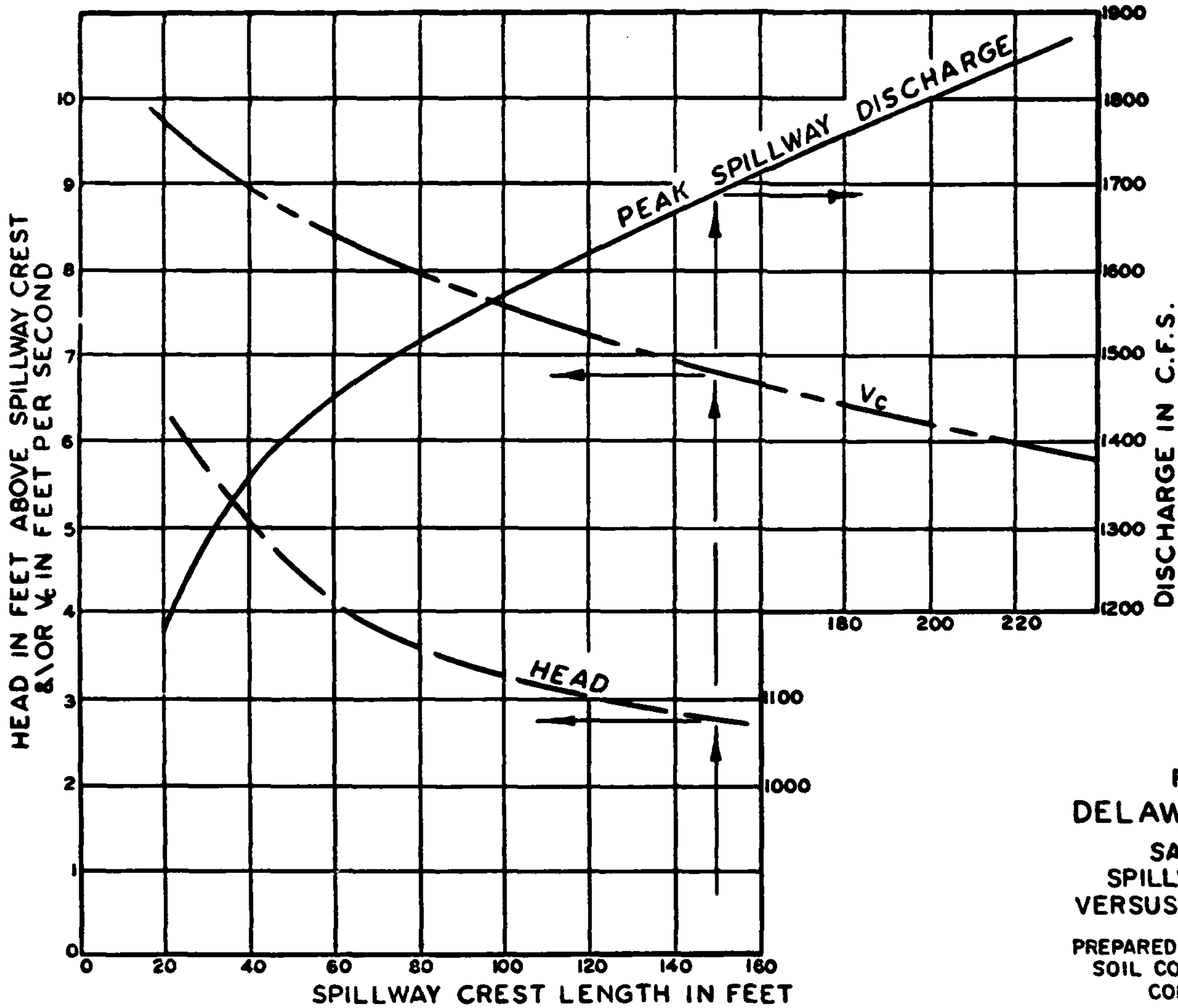


Problem Area	Runoff Curve Number
1	69
2	70
3	73
4	75
5	82
6	73

REVIEW REPORT
DELAWARE RIVER BASIN
PROBLEM AREAS AND RUNOFF CURVE NUMBER

PREPARED BY THE JOINT WORK GROUP
SOIL CONSERVATION SERVICE AND
CORPS OF ENGINEERS

PLATE 10



NOTES:

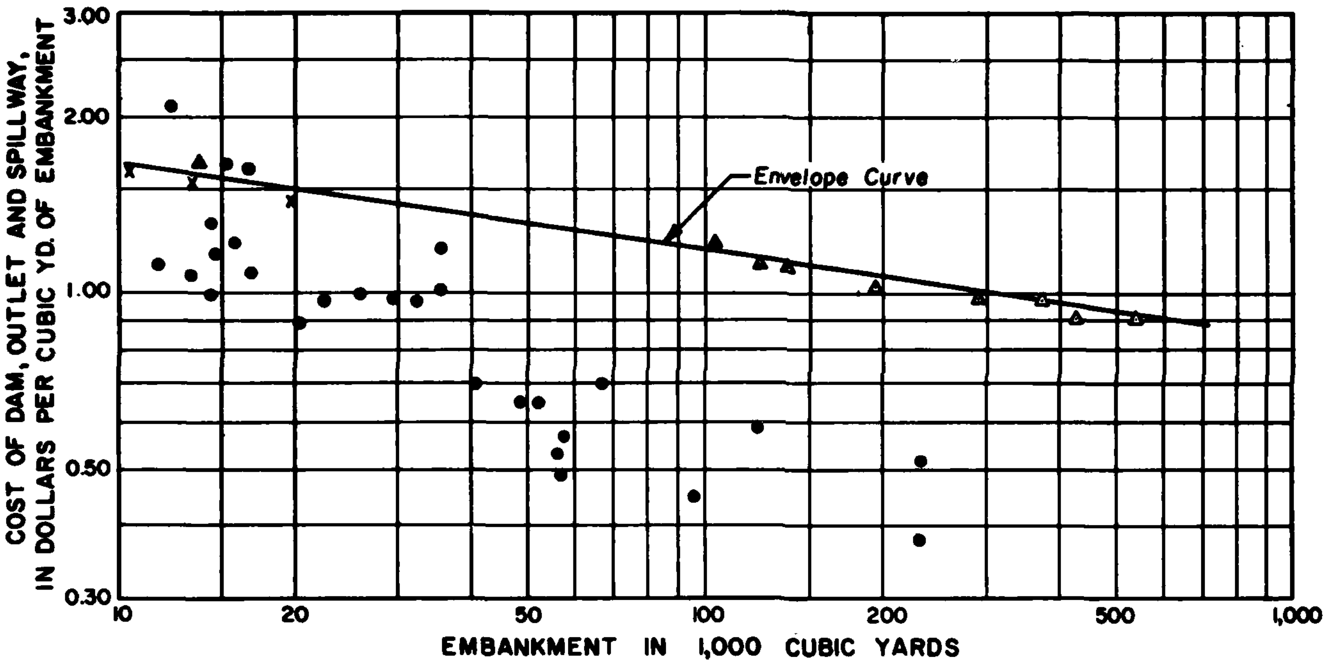
1. Standard project flood routed thru reservoir.
2. Start at bottom of flood control pool.
3. Spillway crest at el. 1540 feet.
4. Flood control storage equals 4 inches of runoff.
5. Principal outlet assumed open.
6. Bottom of flood control at el. 1474 feet.
7. Stream bed at el. 1450 feet.

SITE - De.9
D.A. = 6.3 sq. mi.

REVIEW REPORT
DELAWARE RIVER BASIN
SAMPLE CURVES OF SPILLWAY CREST LENGTH VERSUS HEAD AND DISCHARGE

PREPARED BY THE JOINT WORK GROUP
SOIL CONSERVATION SERVICE AND
CORPS OF ENGINEERS

PLATE 11



▲ Estimates based on experience prices for major control projects.

x Bid prices for small dams built as elements of Watershed Programs in Penna.

● Estimates of small dams built as elements of Watershed Programs in West Virgina, Virgina and Maryland.

Prices plotted are exclusive of the cost of lands, relocations, seeding, fencing, engineering, administration and contingencies.

All bid prices and estimates have been adjusted to the January 1959 price level.

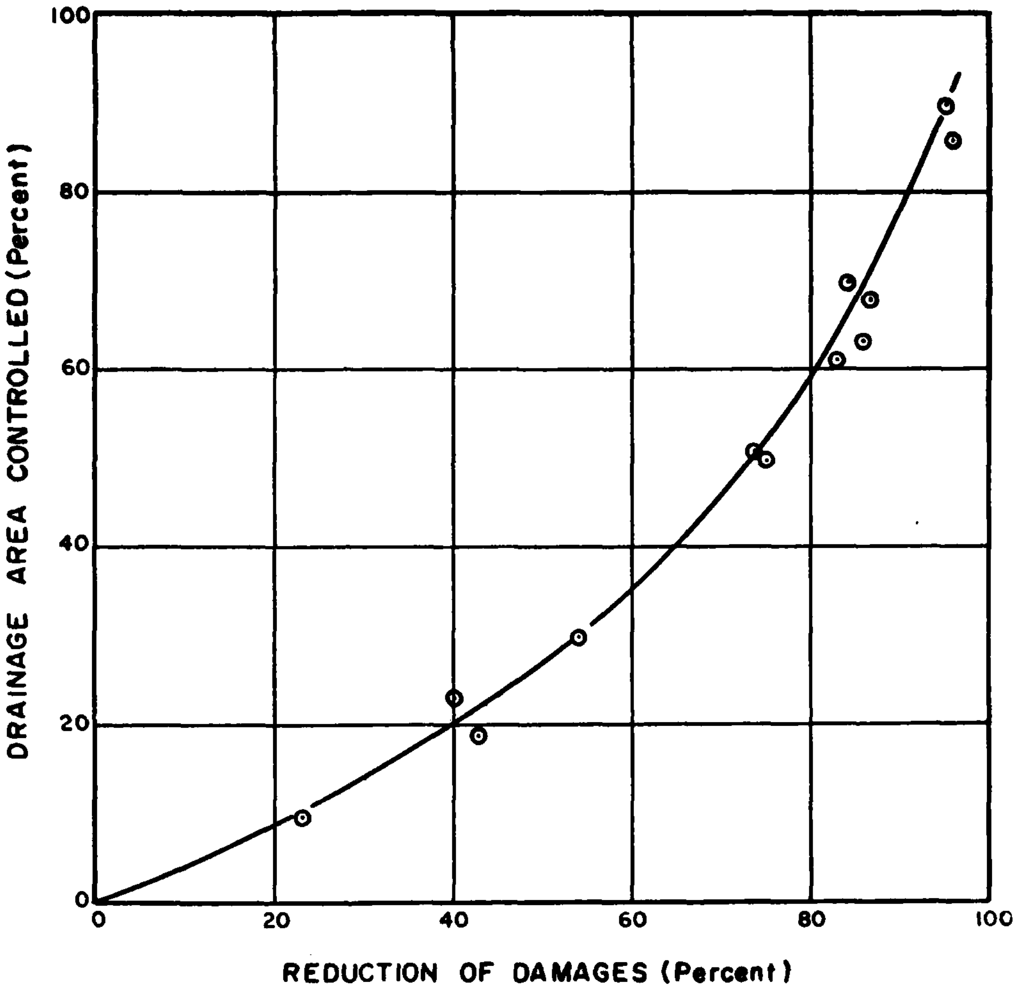
Unit costs taken from this graph are to be used for sites above areas of average damage potential. Additional construction measures may be required at sites above areas of high damage potential.

REVIEW REPORT

DELAWARE RIVER BASIN

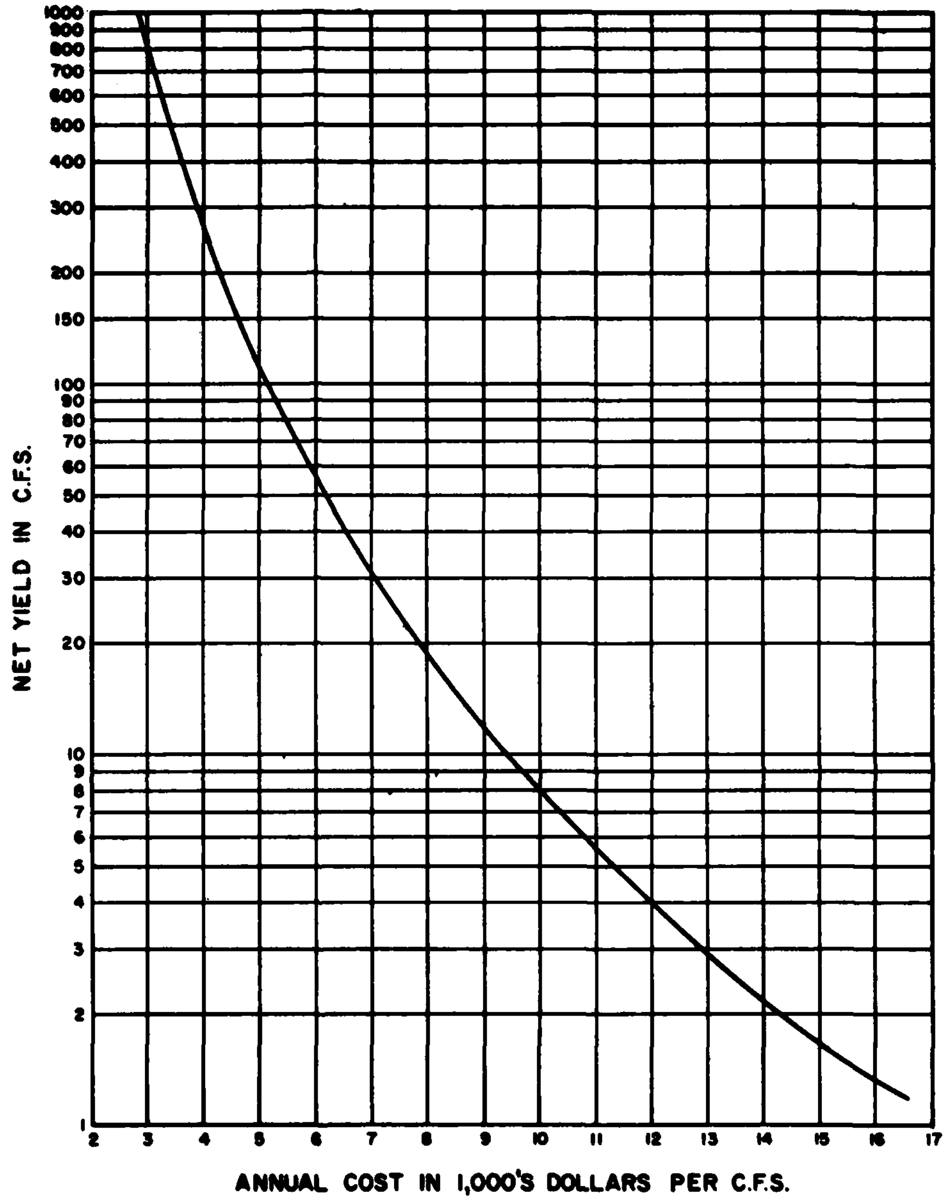
COST OF SMALL DAMS

PREPARED BY THE JOINT WORK GROUP
SOIL CONSERVATION SERVICE AND
CORPS OF ENGINEERS



REVIEW REPORT
DELAWARE RIVER BASIN
GENERALIZED CURVE OF DRAINAGE AREA CONTROLLED VS. FLOOD DAMAGE REDUCTION
PREPARED BY THE JOINT WORK GROUP
SOIL CONSERVATION SERVICE AND
CORPS OF ENGINEERS

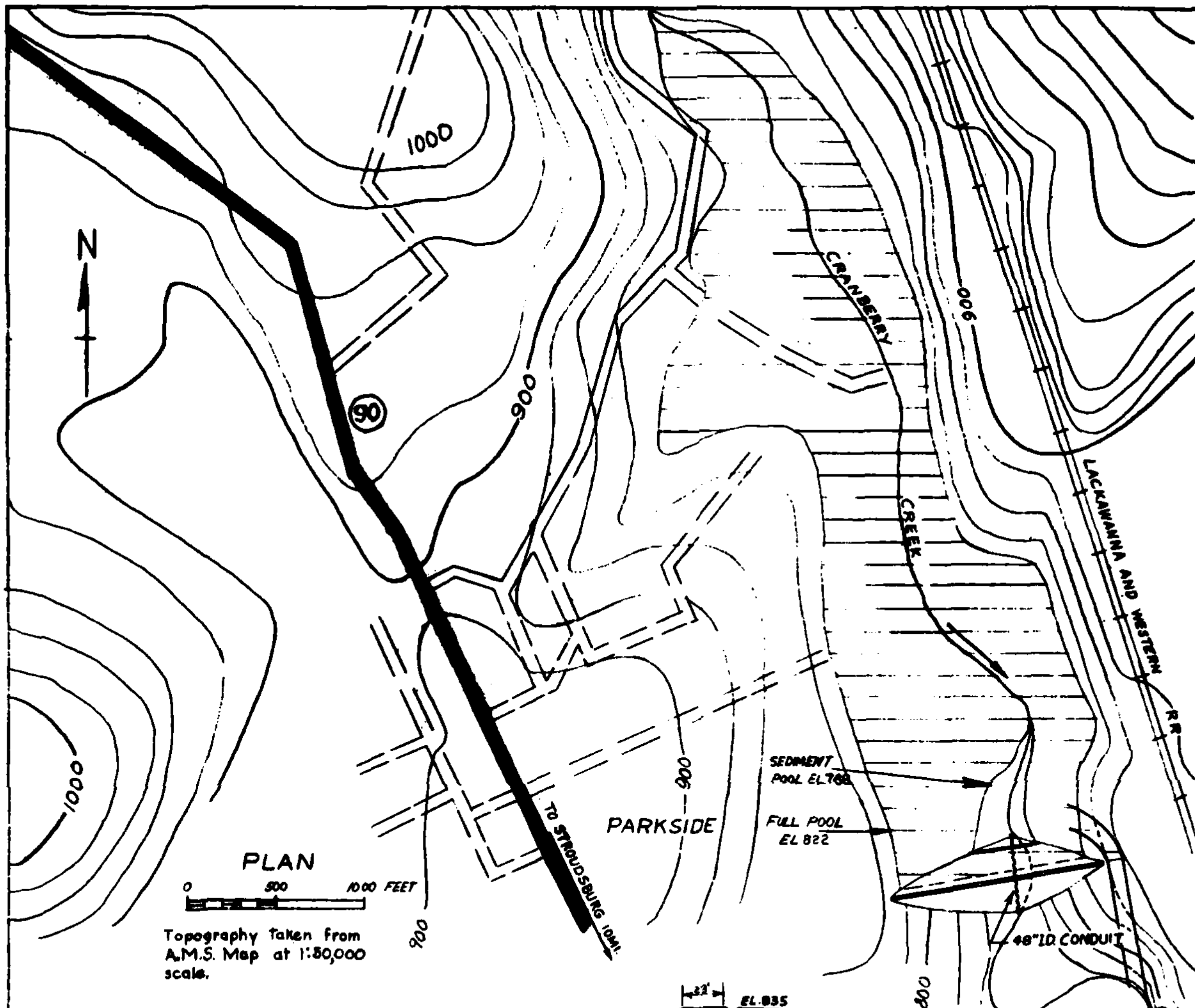
PLATE 13



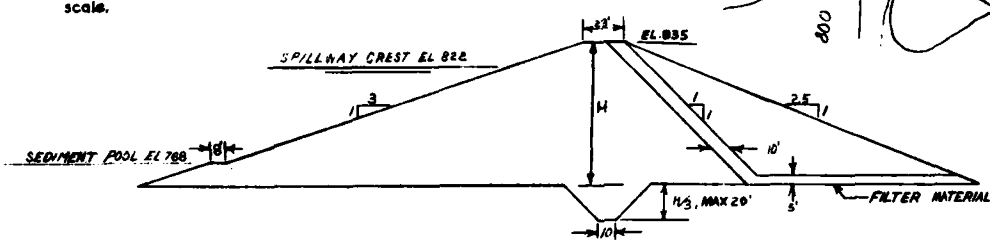
REVIEW REPORT DELAWARE RIVER BASIN

YIELD-COST RELATION

PREPARED BY THE JOINT WORK GROUP
SOIL CONSERVATION SERVICE AND
CORPS OF ENGINEERS

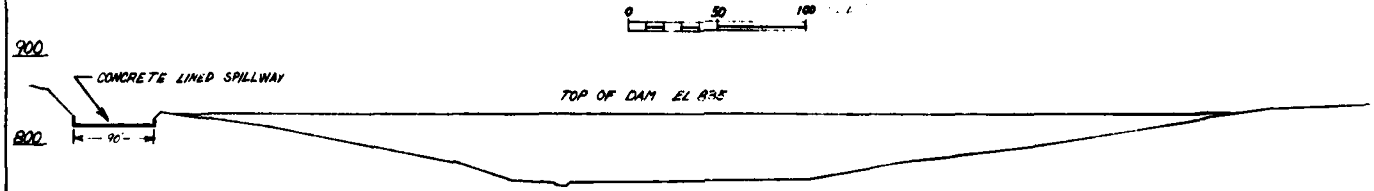


PLAN



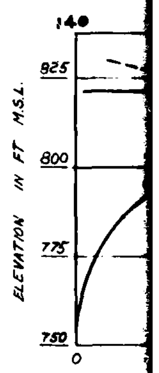
TYPICAL EMBANKMENT SECTION

0 50 100

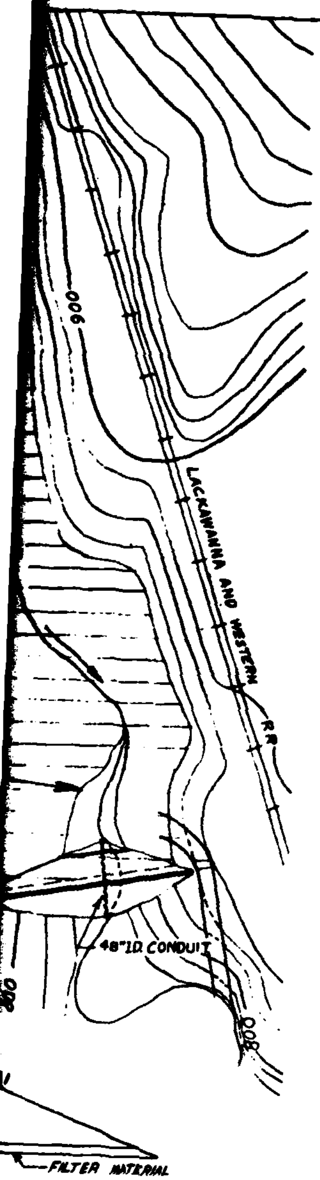


VALLEY SECTION
(Facing downstream)

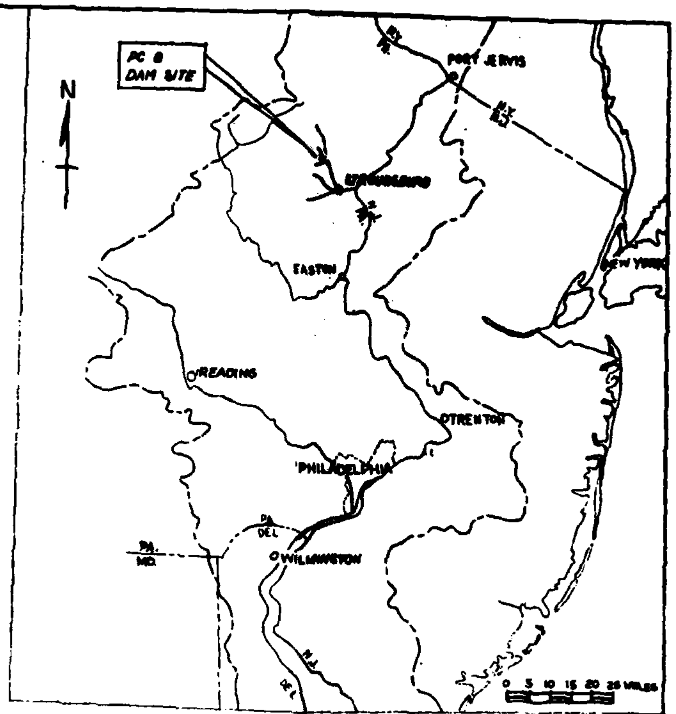
0 100 200 FEET



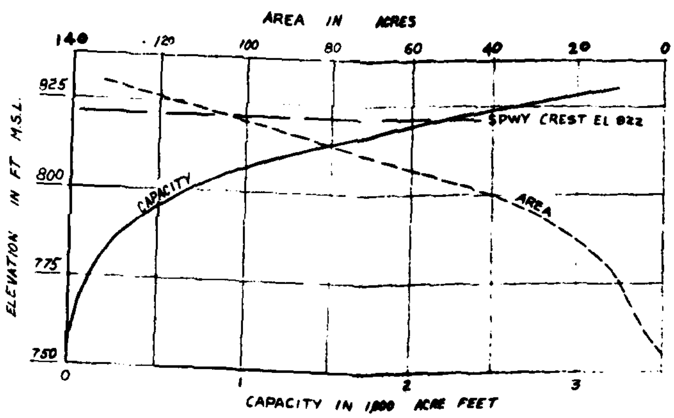
1



ON



LOCATION MAP



AREA AND CAPACITY CURVES

REVIEW REPORT DELAWARE RIVER BASIN

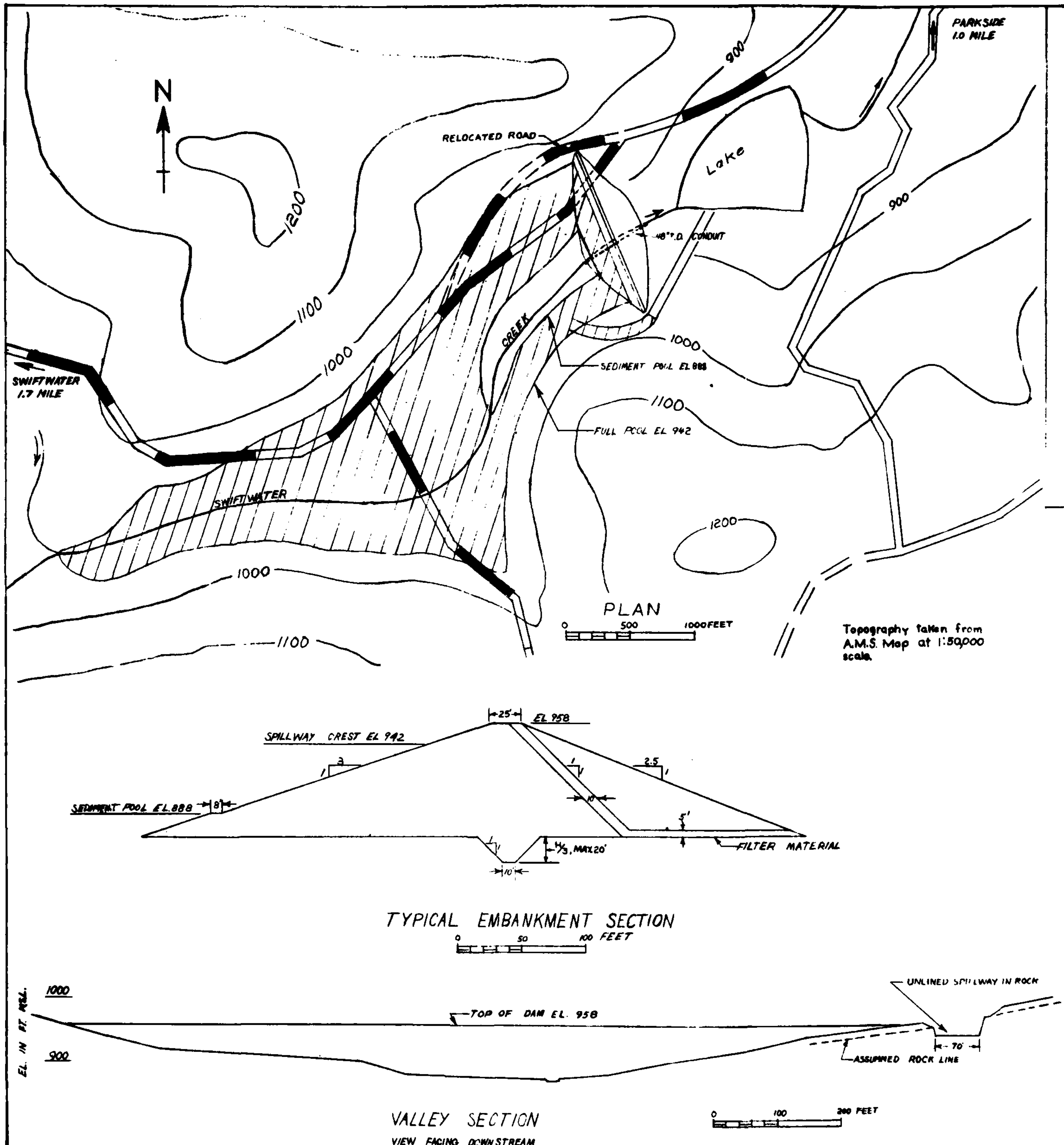
PARKSIDE PROJECT (Pc 8)

Prepared by the Joint Work Group
Soil Conservation Service and
Corps of Engineers

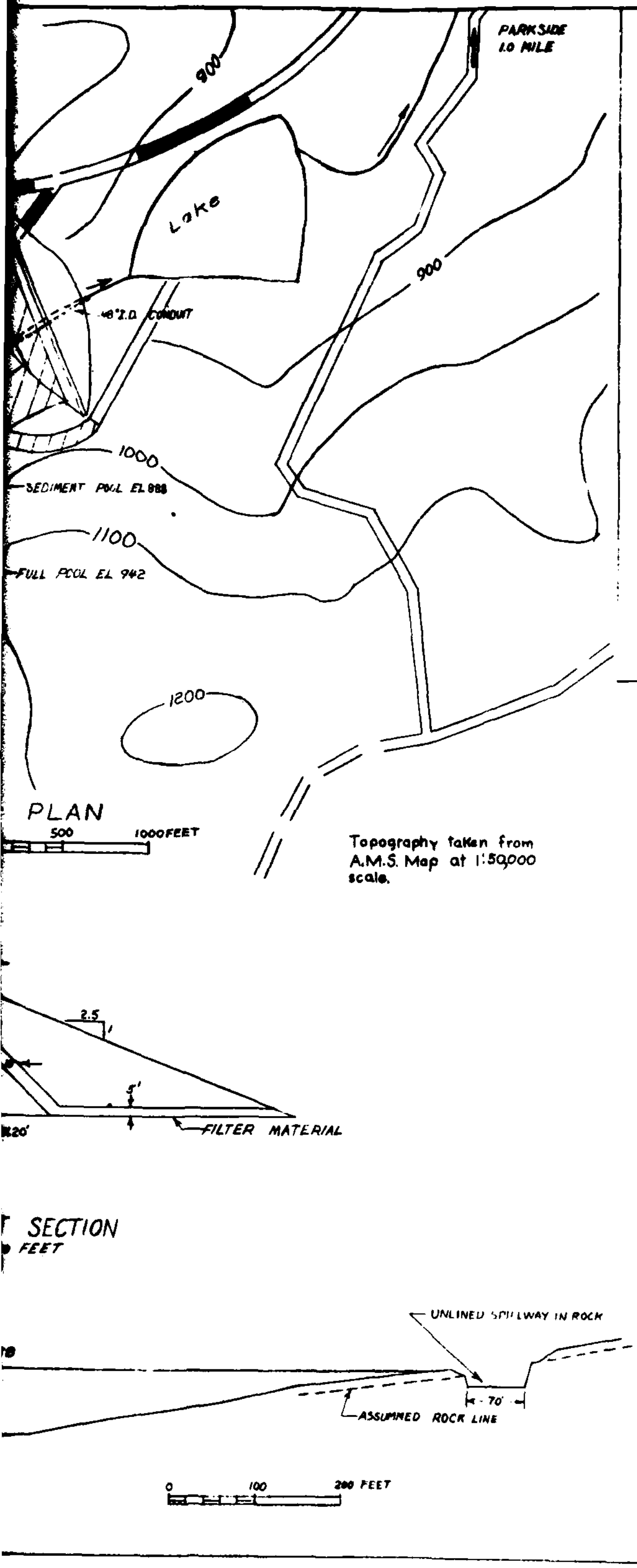
Drawer No 228 File No. 29136

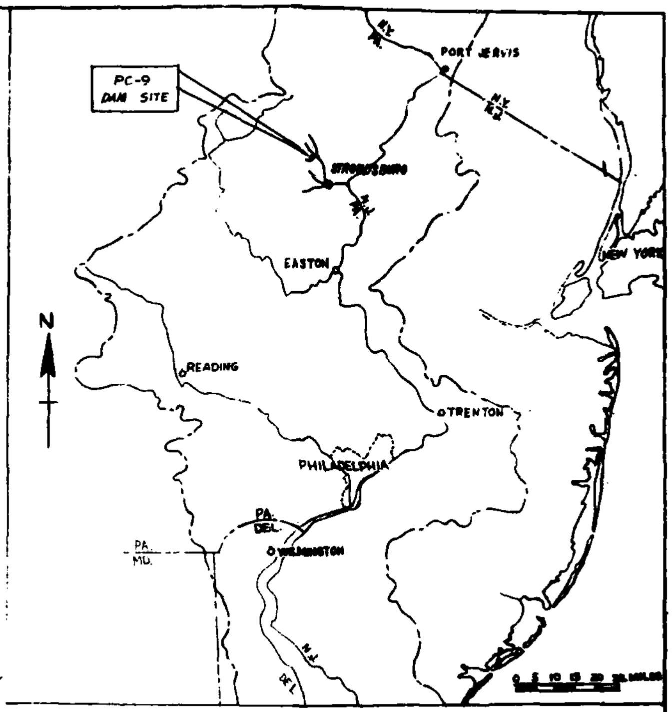
PLATE 15

2

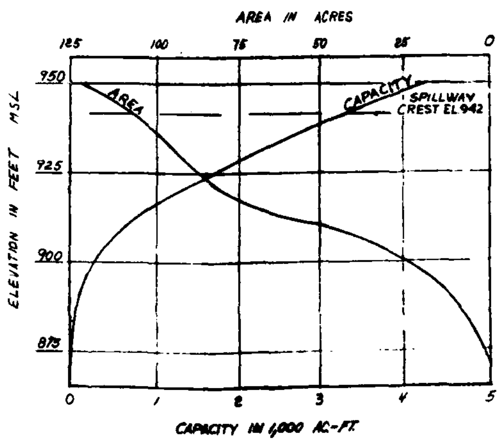


PARKSIDE 1.0 MILE
N
RELOCATED ROAD
900
Lake
1200
48" I.D. CONDUIT
1100
1000
CREEK
SEDIMENT POOL EL 888
SWIFTWATER 1.7 MILE
FULL POOL EL 942
SWIFTWATER
1200
1000
1100
PLAN
0 500 1000 FEET
Topography taken from A.M.S. Map at 1:50,000 scale.
25'
EL 958
SPILLWAY CREST EL 942
3
1
2.5
1
1
1
SEDIMENT POOL EL 888
8'
10'
5'
1
1
H/3, MAX 20'
10'
FILTER MATERIAL
TYPICAL EMBANKMENT SECTION
0 50 100 FEET
EL IN FT. MSL.
1000
900
TOP OF DAM EL. 958
UNLINED SPILLWAY IN ROCK
70'
ASSUMED ROCK LINE
VALLEY SECTION
VIEW FACING DOWNSTREAM
0 100 200 FEET





LOCATION MAP



AREA AND CAPACITY CURVES

REVIEW REPORT DELAWARE RIVER BASIN

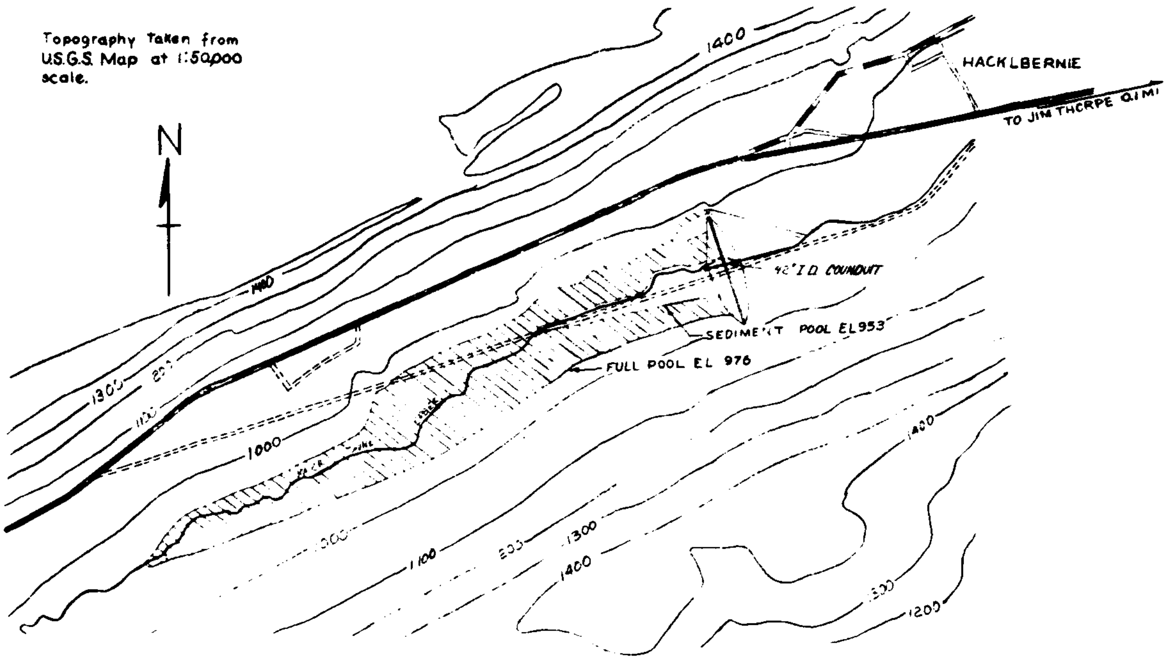
SWIFTWATER PROJECT (Pc 9)

Prepared by Joint Work Group
Soil Conservation Service and
Corps of Engineers

Drawer No. 228 File No. 29134

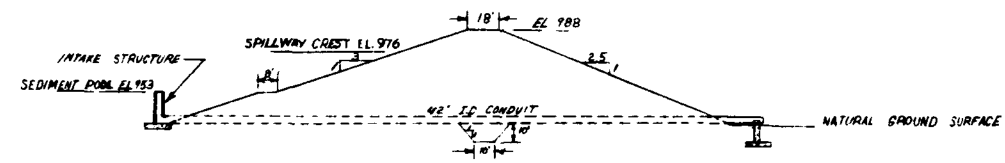
PLATE 16

2



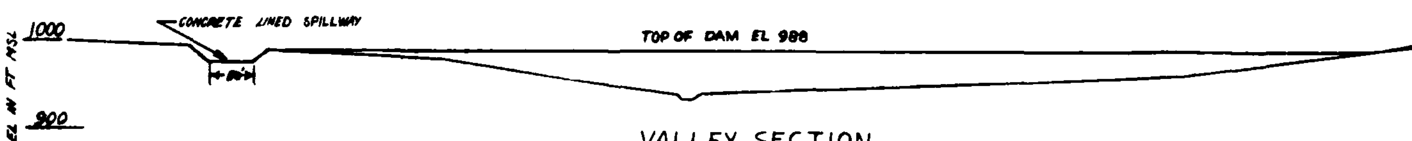
PLAN

0 1000 2000 FEET



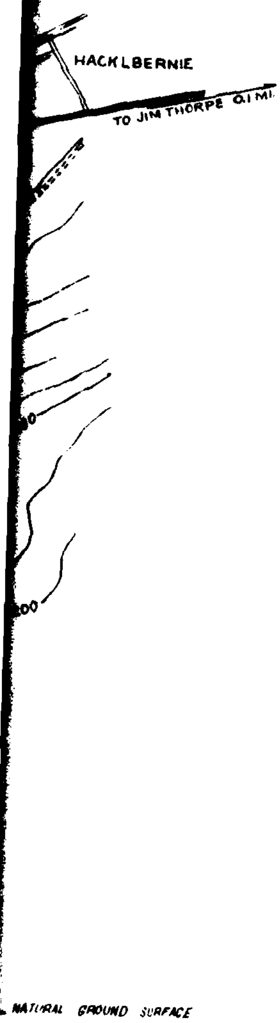
TYPICAL DAM SECTION

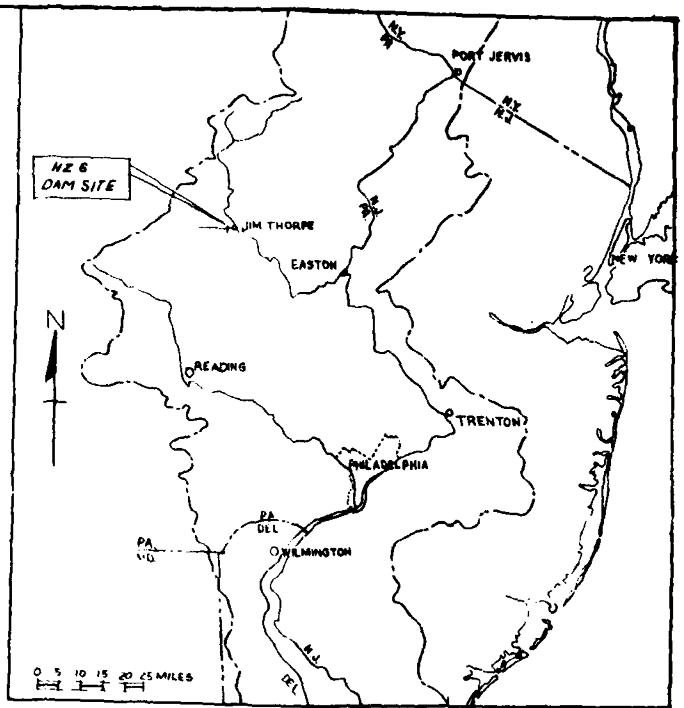
0 50 100 FEET



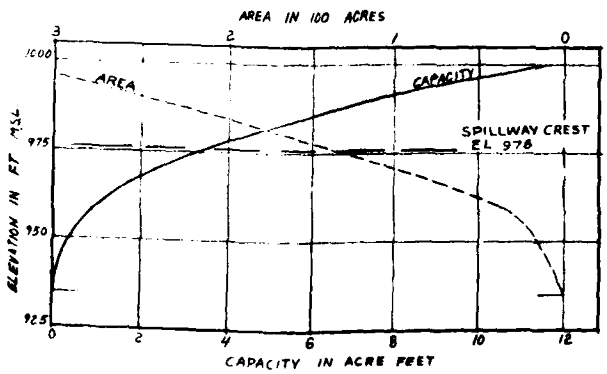
VALLEY SECTION
(FACING DOWNSTREAM)

0 100 200 FEET





LOCATION MAP



AREA AND CAPACITY CURVES

REVIEW REPORT DELAWARE RIVER BASIN

JIM THORPE PROJECT (Hz 6)

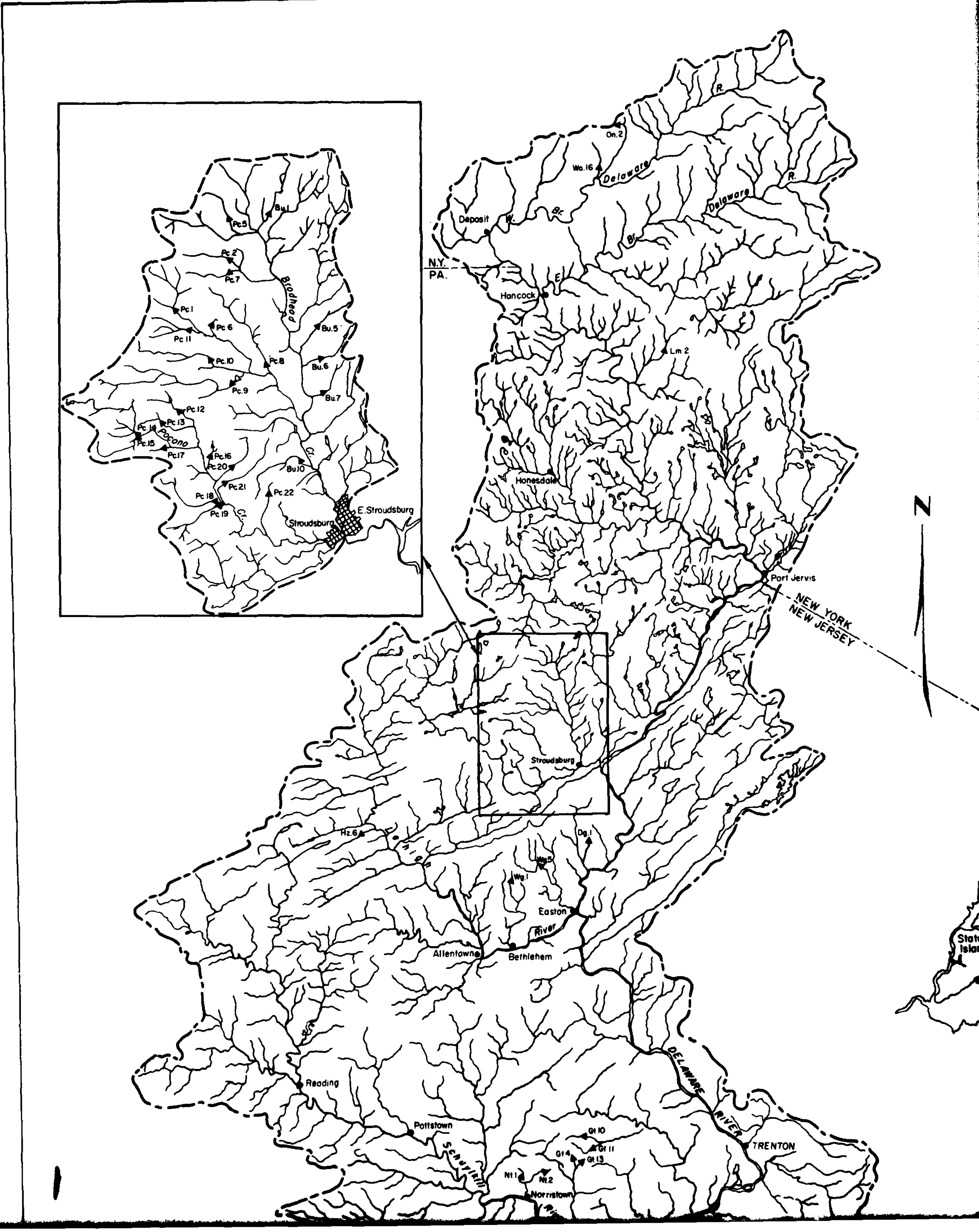
Prepared by the Joint Work Group
Soil Conservation Service and
Corps of Engineers

Drawer No. 228 File No. 29135

PLATE 17

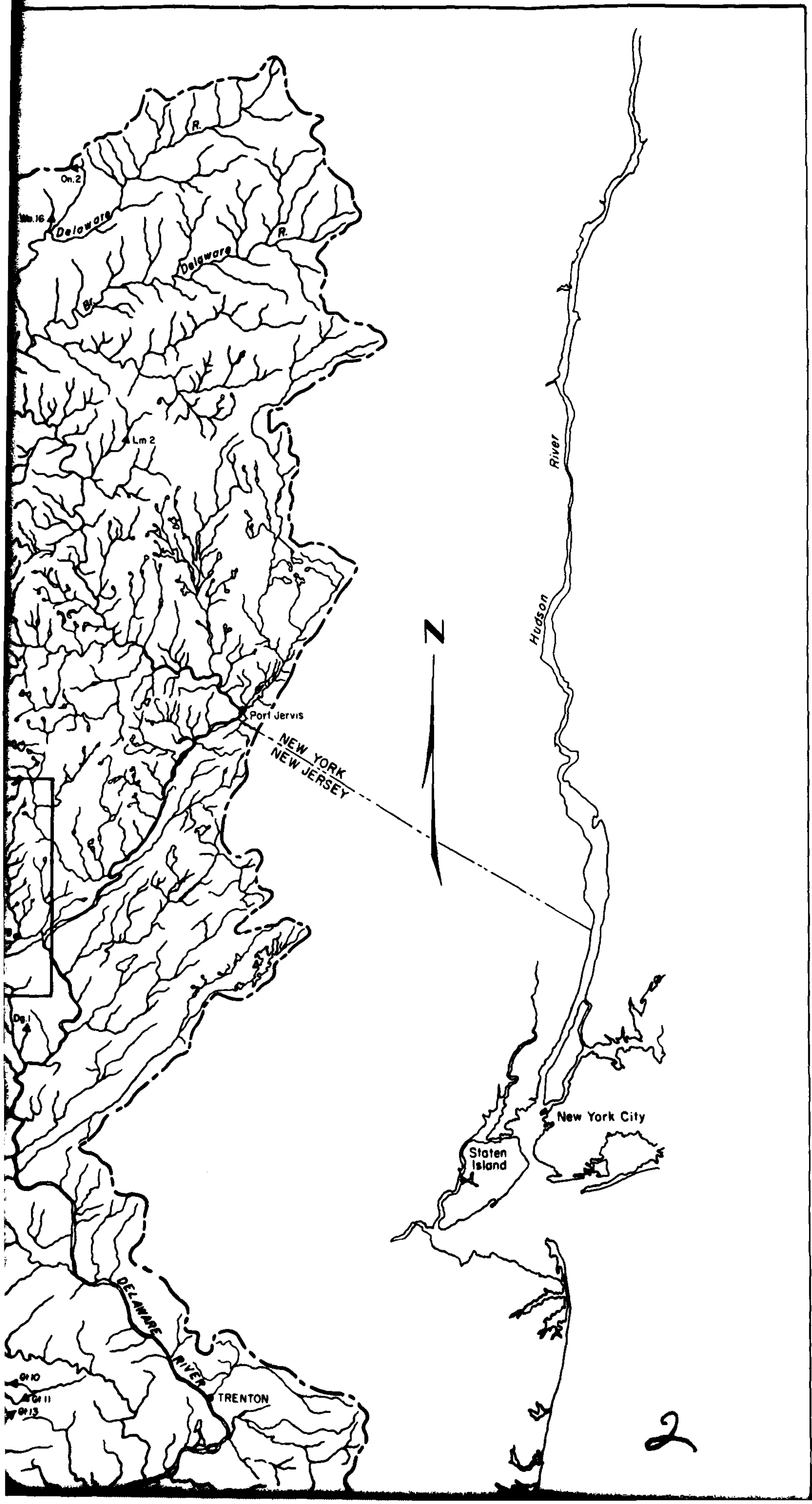
2

CORPS OF ENGINEERS



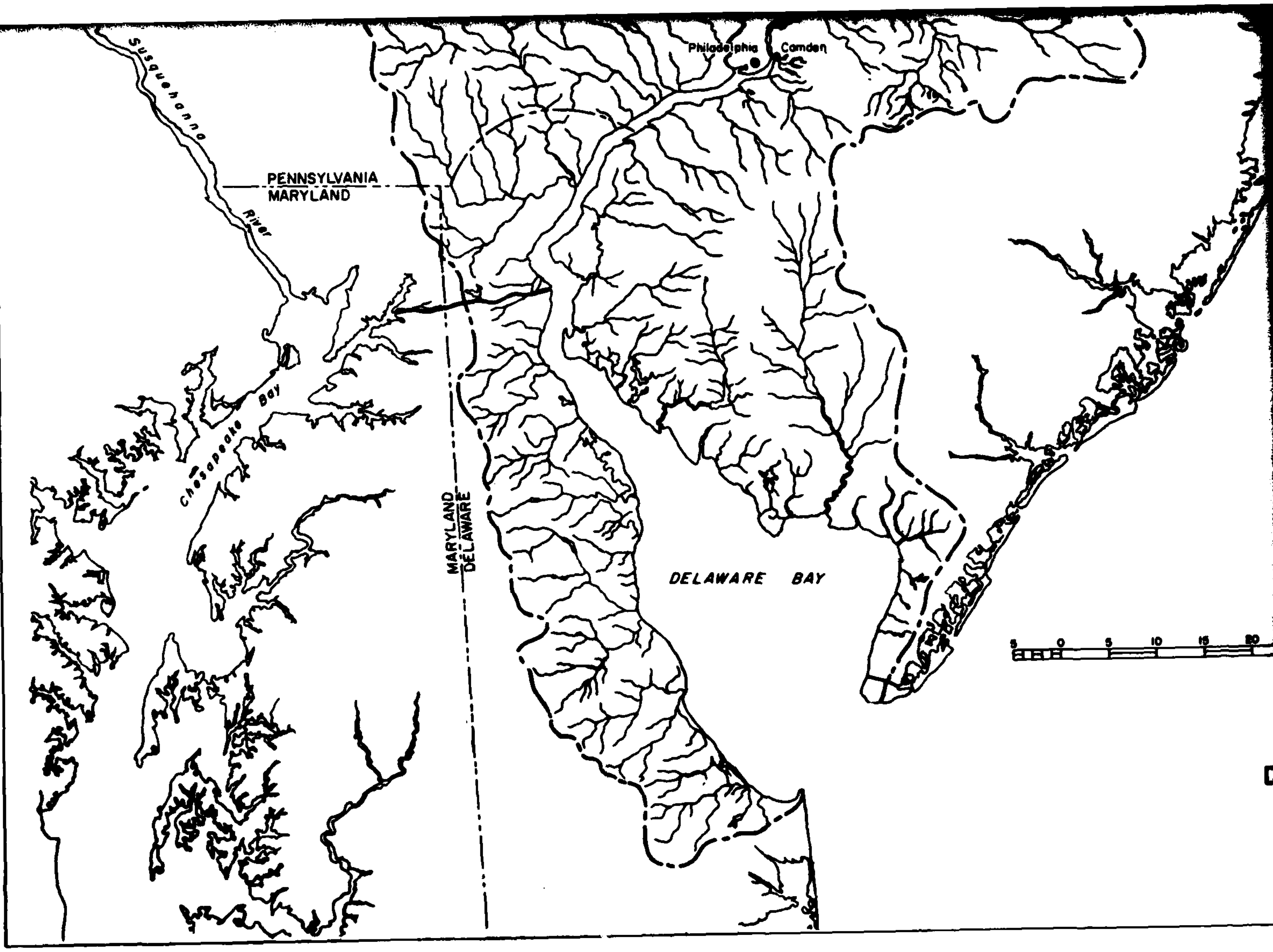
1

U.S. ARMY

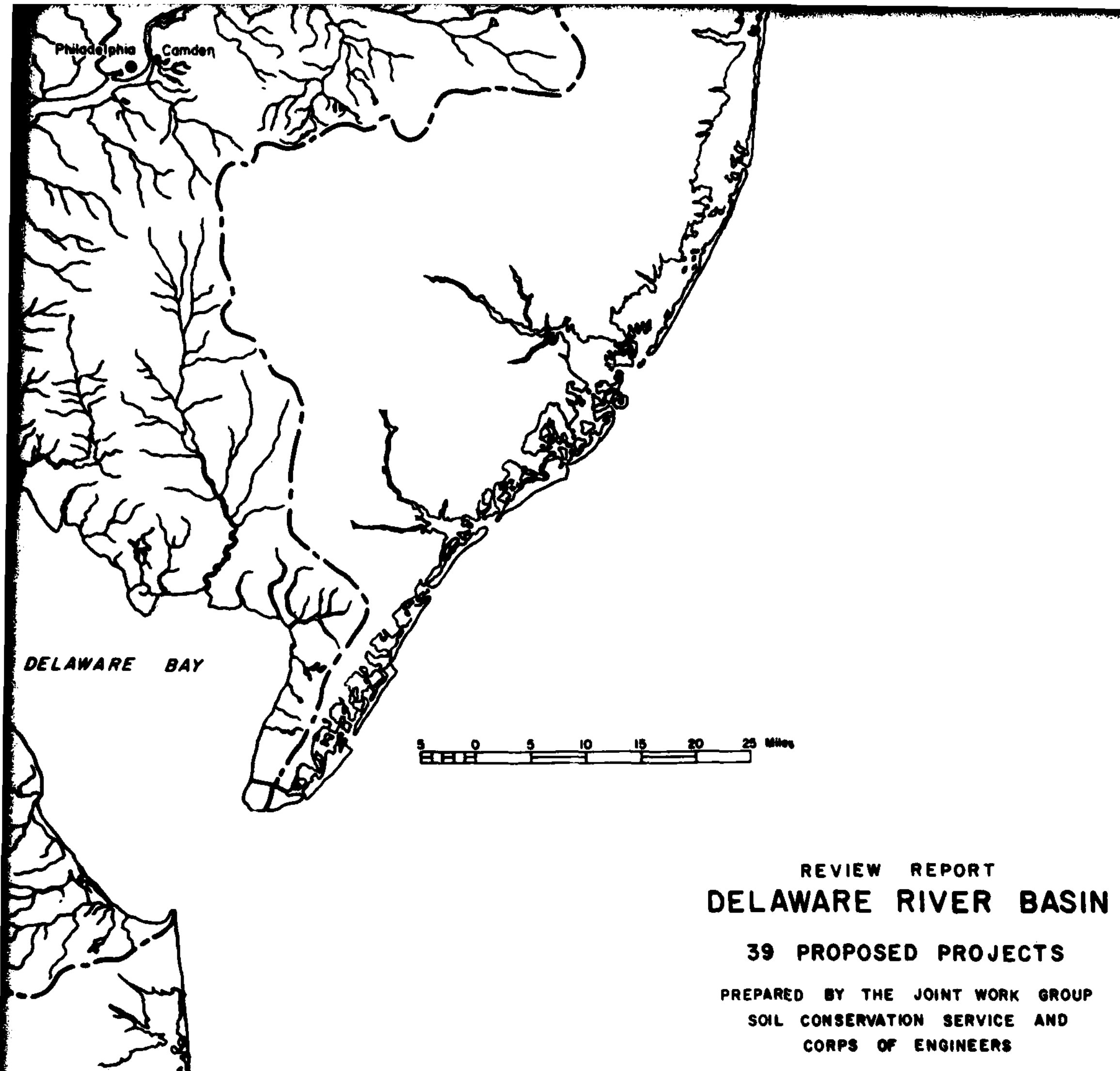


On.2
Delaware
R.
Delaware
R.
Br.
Lm 2
Port Jervis
NEW YORK
NEW JERSEY
N
Hudson
River
Dg.1
New York City
Staten
Island
DELAWARE
RIVER
TRENTON

2


Philadelphia
Camden
Susquehanna
River
PENNSYLVANIA
MARYLAND
Chesapeake Bay
MARYLAND
DELAWARE
DELAWARE BAY
5 0 5 10 15 20

3



REVIEW REPORT

DELAWARE RIVER BASIN

39 PROPOSED PROJECTS

PREPARED BY THE JOINT WORK GROUP
SOIL CONSERVATION SERVICE AND
CORPS OF ENGINEERS

PLATE 18

4

REPORT ON THE

COMPREHENSIVE SURVEY

OF THE

WATER RESOURCES

OF THE

DELAWARE RIVER BASIN

APPENDIX S

SALT WATER BARRIER

PREPARED BY THE
U. S. ARMY ENGINEER DISTRICT, PHILADELPHIA
CORPS OF ENGINEERS
PHILADELPHIA, PA.

CONTENTS

CONTENTS

CONTENTS

TABLES

PLATES

ATTACHMENTS

APPENDIX S

SALT WATER BARRIER

SECTION I - AUTHORITY

1-01. The District Engineer has been directed to submit a report on the Delaware River pursuant to the following resolution adopted 28 April 1958 by the Committee on Public Works of the United States Senate:

> "Resolved by the Committee on Public Works of the United States Senate, that the Board of Engineers for Rivers and Harbors, created under Section 3 of the River and Harbor Act, approved June 13, 1902, be, and is hereby, requested to review the reports of the Chief of Engineers on the Delaware River, New York, New Jersey and Pennsylvania, contained in House Document numbered 179, Seventy-third Congress, Second Session, and other reports, in conjunction with the pending comprehensive survey of said stream, with a view to determining the feasibility of construction of a barrier in the Delaware estuary, such study to consider the economic and physical effects of such a structure, the costs and potential benefits of the structure, and the economic and physical relationship of such a structure to other works of improvement now being planned for the Delaware River Basin."

SECTION II - PURPOSE AND EXTENT OF STUDY

2-01. The purpose of this study is to make a preliminary analysis of the economic feasibility of the proposed barrier with a view to determining if justification exists for making detailed studies of all aspects of the proposal.

2-02. The work required for this preliminary analysis consisted of the following four main features: (a) field investigations; (b) model tests; (c) a study and report, by a consulting engineer firm, on other possible sources of fresh water supply; and (d) office studies and preparation of the report. The field investigations were limited in extent, consisting principally of reconnaissance and inspection of possible site locations. The office studies included: (a) the assembly and processing of data on future water requirements; (b) an analysis of the effect a barrier would have on navigation and channel maintenance, fish and wildlife, recreation, shore lines, structures, storm and sanitary sewage systems, and flooding from hurricane surges; (c) preliminary design of the barrier, locks and other required facilities, and (d) a preliminary economic analysis to serve as the basis for conclusions. The views of local interests were obtained at a public hearing and are summarized in paragraphs 6-02 and 6-03. Throughout the

course of studies interested parties were consulted frequently to obtain information necessary for the study.

2-03. The model tests made in connection with this study were conducted at the Waterways Experiment Station, Vicksburg, Mississippi. Tests were made to determine the best type of a barrier and its effect on tides, current and salinity. Models of two types of salt water barriers were tested. The details and results of the tests are discussed in Section VII and are presented in detail in attachment 1.

2-04. The study made by the consulting engineer firm was to determine the feasibility of obtaining the needed fresh water from the Delaware River without a barrier or from sources other than the Delaware River. The study was the basis for development of alternate plans which are discussed in Section IX of this appendix.

2-05. The primary consideration in determining the location of the barrier was to find a site to create a large fresh water pool that would provide water for northern Delaware. It was determined that the barrier should be placed north of the entrance to the Chesapeake and Delaware Canal so that the tidal regimen of this sea-level canal would not be radically changed. Consideration of these factors placed the barrier in the New Castle-Delaware City area. Three sites in this area were studied and the recommended site was chosen because (a) it provides the best approaches for vessels to the locks (b) minimum width of river for barrier construction (c) minimum interference with existing improvements.

SECTION III - DESCRIPTION

3-01. GENERAL. The site proposed for the barrier structure is located just downstream of New Castle, Delaware and Penns Beach, New Jersey, crossing Delaware River ship channel in the Deepwater Point Range about 34 miles below Philadelphia, Pennsylvania. The location is shown on plate S-1. The general vicinity of the proposed structure is shown on United States Coast and Geodetic Survey Chart No. 294; and on Army Map Service, Series V832, Sheets 5863 II NE, Wilmington South and 5963 III, NW, Penns Grove, Scale 1:25,000. On the Delaware side of the river the barrier site crosses a marsh area and Army Creek, a small creek presently controlled by tide gates. The land adjoining the marsh rises to an elevation suitable to form a terminus for the barrier. The Delaware River frontage through this section is defined by a tidal dike fronted by a shoal or mud flat which becomes partly exposed at low tide. The New Jersey shore of the Delaware River in the vicinity of the barrier site consists of marsh extending up and down the river from the proposed site. The marsh is partially backed up by a dike, and fronts generally on relatively low flat land, some of which has been used as a disposal area for material dredged from the

Delaware River Channel. The area is drained by tidal streams flowing through marshes. The low land and marsh extend a considerable distance back from the river.

3-02. TIDES. The Delaware River and Bay are tidal from the Capes to Trenton, N. J. with the mean range of tide varying from 4.1 feet at the Capes to about 6.9 feet at the head of tide at Trenton, a distance of 133 miles. The mean low water elevations vary from 1.1 feet (referred to Delaware River datum, which is 2.9 feet below mean sea level) at the mouth, to 0.2 foot at Ship John Light, to 0.5 foot at Reedy Point, and thence remaining at approximately 0.5 foot to Philadelphia and increasing to 0.8 foot at Trenton. The normal high water changes gradually from 5.2 feet at the mouth, to 6.5 feet at Philadelphia and 7.7 feet at Trenton. During spring phases of the periodic tide changes, the range of tide increases 0.8 foot at the Capes and 0.3 foot at Philadelphia. At the proposed location of the barrier, 3,500 feet downstream of New Castle, Del. the normal range of tide under existing conditions is 5.5 feet, and the high water is 6.0 feet.

3-03. The tides in the estuary are affected by storm conditions which influence the ocean in the vicinity of the Capes, and by the added influence of the local winds in the estuary. Storm winds from the quadrant ranging from northeast to the southeast result in abnormally high tides. During the storm of November 1950 the high stages from the upper end of Delaware Bay to above Philadelphia were 5 feet to 5½ feet above normal high water. The maximum stages below Philadelphia have been experienced during extreme wind storms which raised the general level of the estuary, while above Philadelphia the high stages are the result of flood flows or a combination of flood and wind effect. This combination occurred during the flood of August 1933, which produced the maximum stage of record at Philadelphia 5.2 feet above normal high water. At the upper end of the estuary, the rate of fresh water discharge is the dominant factor in producing high stages. During the maximum flood of record, August 1955, the peak stages at Burlington and Trenton were, respectively, 6.5 feet and 13.2 feet above normal high water. The peak flood flow of the Delaware River at Trenton during this flood was 329,000 cfs, as compared to a mean daily flow of about 12,000 cfs.

3-04. During northwest winds of long duration the tides in the Delaware are lowered as much as 4.5 feet below normal at some locations. At New Castle, Delaware, in March 1932 an extreme low water was experienced with an elevation of 4.0 feet below mean low water.

3-05. Wave action in the estuary is, of course, variable as to location and magnitude. In the breaker zone of the ocean near the Capes, waves as high as 15 feet have been reported. Derived data using hindcasting methods indicate that waves of at least 6 feet in height occur in the ocean off the Delaware Bay entrance about 15 percent of the time.

In Delaware Bay, waves of 6 feet to 7 feet have been experienced, and 4 foot waves occur about once a year. In the vicinity of New Castle waves 2 feet to 3 feet in height have been experienced during unusual storm conditions.

3-06. GEOLOGY. The proposed location of the barrier lies entirely within the Atlantic Coastal Plain physiographic province. 1/ This province is underlain generally by unconsolidated sediments that slope gently southeastwardly from the eastern part of the State of Delaware and continue across the State of New Jersey to the Atlantic Ocean. Bedrock in this region is found at a depth of about 500 feet near U. S. Route 13 in Delaware, and at about 850 feet at Finns Point Rear Light in New Jersey. The Coastal Plain deposits which are unconsolidated sediments overlaying the bedrock, include marl, silt, clay, sand and gravel. Above these formations are the undifferentiated clays, silts, sands and gravels of Pleistocene glaciation and recent origin. Along the axis of the proposed dam the Delaware River channel cuts into silt, which has been determined from borings to occur at a maximum depth of approximately 90 feet below mean sea level. Since the present course of Delaware River flows in unconsolidated sediments, it is believed that its course followed other channels in the past. One course may have paralleled the present one in the vicinity of some segments of the Salem River, where similar but variable thicknesses of silts, clays and organic matter occur.

3-07. TRIBUTARY AREA. The area considered tributary to Delaware River commerce extends throughout the Trunk Line and Central Freight Association rate territories as established by the Interstate Commerce Commission, comprising the States of New Jersey, New York, Pennsylvania, Delaware, Maryland, West Virginia, Ohio and Indiana and District of Columbia; and some stations in Virginia, North Carolina, Kentucky, Michigan, Illinois, Wisconsin, Missouri, and Iowa. The local area that is served by the Delaware River ship channel extends from Trenton, New Jersey to Delaware Bay. The area adjacent to the river upstream from New Castle, Delaware is almost entirely industrial, and contains numerous large manufacturing and processing plants of national significance in the character and volume of their products. Many smaller industries contribute a large volume and diversity of commodities. Local interests have kept abreast of the Federal Government's improvement of the channel through the development of public and private wharves and terminals. Wharves and docks, warehousing and storage space, handling facilities and auxiliary services are numerous and conveniently located. There are several shipyards on Delaware River capable of constructing or handling any size or type of ship for major overhaul and repair.

1/ See Appendix N, "General Geology and Ground Water."

3-08. The tidal portion of Delaware River and its tributary streams above New Castle, Delaware is of primary concern in this appendix. The area adjacent to these streams is served by extensive highway, rail, air and water transportation facilities. This area has become highly developed to include large centers of population and industry. Residential and commercial development has kept pace with industrial growth and population increases. Some of the larger cities and towns along the tidal reaches of Delaware River and tributaries above the barrier site include: New Castle and Wilmington in the state of Delaware; Marcus Hook, Chester, Philadelphia, Bristol, and Morrisville in Pennsylvania; and Trenton, Bordentown, Burlington, Mt. Holly, Riverside, Palmyra, Camden, Gloucester, Woodbury, Paulsboro, and Pennsgrove in the State of New Jersey. The combined population according to the 1950 census, of these cities and towns was 2,607,854 of which 2,071,605 was for Philadelphia.

3-09. BRIDGES. Eight highway bridges and three railroad bridges cross Delaware River in the tidal area between the barrier site and Trenton. In addition, many bridges cross Delaware River tributaries in the tidal area upstream of the proposed barrier. Pertinent data on these bridges are presented in attachment 2.

SECTION IV - PRIOR REPORTS

4-01. The resolution which authorized the investigation of a barrier in Delaware estuary requested a review of reports of the Chief of Engineers on the Delaware River, New York, New Jersey, and Pennsylvania, contained in House Document 179, Seventy-third Congress, Second Session, and other reports. That Document is a preliminary examination report (the Delaware River "308" report) on the Delaware River watershed which was transmitted to Congress on 9 October 1933. Although the report considered all phases of water resources development for the watershed, no serious consideration was given to developing the lower river for water supply because of the poor quality of the water. The report recommended that water resource development be coordinated and that potential power and other uses of the upper river be kept subordinate to water supply demands. In his review of the report, the Chief of Engineers concluded that no additional improvements for navigation, power development, flood control, irrigation, water supply, or any combination thereof, should be undertaken at that time.

4-02. Three other prior reports are considered pertinent for consideration in the current investigation of a barrier in the Delaware estuary. These reports are summarized in the following sub-paragraphs:

a. A review report (survey) dated 15 February 1937 on Delaware River between Philadelphia and the Sea was printed as Senate Document No. 159, 75th Congress, 3rd Session. In this report, the Chief of Engineers recommended modification of the Philadelphia to the Sea project to provide for a channel 37 feet deep from Philadelphia-Camden Bridge to the Naval Base; thence 40 feet deep to deep water in

Delaware Bay, 800 feet wide in the straight reaches from the bridge to a point in Delaware Bay near Ship John Light; thence 1,000 feet wide to deep water in Delaware Bay, with 1,200 feet width at Bulkhead Bar, 1,000 feet width at other bends and in Philadelphia Harbor; provided that the cities of Philadelphia and Camden agree to dredge not less than 110,000 cubic yards annually in maintaining the channel and anchorage in Philadelphia between Allegheny Avenue and the mouth of Schuylkill River. These recommendations were adopted by Congress in the River and Harbor Act of 20 June 1938.

b. A review report (survey) dated 13 January 1953 on Delaware River between Philadelphia, Pa., and Trenton, N. J., and Philadelphia to the Sea, was printed as House Document No. 358, 83rd Congress, 2d Session. In the report, the Chief of Engineers recommended modification of the Philadelphia to the Sea project to provide for deepening the channel from the Naval Base to Allegheny Avenue to 42 feet in rock and 40 feet in other material. This report also recommended modification of the Philadelphia to Trenton project to provide for enlarging the existing channel from Allegheny Avenue to Newbold Island to a depth of 42 feet in rock and 40 feet in other material and a width of 400 feet with suitable widenings at bends; and for deepening the existing channel from Newbold Island to Trenton Marine Terminal to 35 feet. These recommendations were adopted by Congress in the River and Harbor Act of 3 September 1954.

c. A review report (survey) dated 17 June 1955 on Delaware River, Philadelphia to the Sea, (Anchorages), was printed as House Document No. 185, 85th Congress, 1st Session. In this report, the Chief of Engineers recommended that the existing project for the Delaware River, Pa., N. J., and Delaware, Philadelphia to the Sea, be modified to provide the following: An anchorage in the vicinity of Mantua Creek 40 feet deep, 2,300 feet wide, and having a mean length of 11,500 feet; an anchorage at Marcus Hook 40 feet deep, 2,300 feet wide, and having a mean length of 13,650 feet; an anchorage in the vicinity of Deepwater Point 40 feet deep, 2,300 feet wide, and having a mean length of 5,200 feet; and an anchorage in the vicinity of Reedy Point 40 feet deep, 2,300 feet wide, and 8,000 feet long. The recommendations made in this report were adopted by Congress in the River and Harbor Act of 3 July 1958.

SECTION V - RELATED INTERESTS AND PROBLEMS

5-01 NAVIGATION.

a. Existing Projects. The Federal navigation project in Delaware River consists of an improved ship channel and six anchorages, one below the proposed barrier site and five above the site. The existing project provides for a channel 40 feet deep and 1,000 feet wide from natural deep water in Delaware Bay to a point in the bay near Ship John Light; thence to Philadelphia Naval Base, 40 feet deep and 800 feet wide, with 1,200-foot width at Bulkhead Bar and 1,000-foot width at other bends. The 40-foot channel extends through the Philadelphia harbor, having appropriate widths to accommodate the harbor facilities, and continues up river to the upstream end of Newbold Island. The channel is 800 feet wide and 40 feet deep in Deepwater Point Range at the site of the proposed barrier. Many of the streams tributary to the Delaware River have been improved for navigation by Federal projects. The streams above the barrier site that have been thus improved are: Christina and Schuylkill Rivers, along the right bank of the Delaware; and Oldmans, Raccoon, Mantua, Woodbury, and Big Timber Creeks, and Cooper and Rancocas Rivers along the left bank.

b. Vessel Traffic. The navigation channel in Delaware River provides access for maritime traffic to one of the most important port areas in the world. Vessel traffic on the Delaware River has been steadily increasing over the years. Records of vessel trips and drafts show that not only the number of trips but also the size of vessels transiting the river have greatly increased since the early navigation improvements were adopted. Table E-5, Appendix E, presents data on trips and drafts of vessels moving in the foreign and coastwise trade on Delaware River between Trenton and the sea for calendar year 1958. This table shows that in 1958 there were approximately 11,000 trips by vessels drawing 19 feet and over in the foreign and coastwise traffic. The majority of deep-draft vessels (drafts of 30 feet and over) were tankers, carrying petroleum and petroleum products to and from the major oil refineries located along the Delaware and Schuylkill Rivers. In 1958 the petroleum industry and the iron and steel industry together accounted for 83 percent of the total foreign and domestic water-borne commerce of the Delaware River port area. For this reason tankers and ore carriers figure prominently in the Delaware River vessel traffic. Because of greater shipping economies, the trend in ship construction is toward an increase in size of tankers and ore carriers. Indicative of the size of the larger oil and bulk ore carriers which trade in Delaware River ports are: the ore carrier "Ore Titan" having a length of 794 feet, a width of 116 feet and a salt water draft of 38 feet 8 inches; and the supertanker "Harold H. Helm" having an overall length of 854 feet, a width of 125 feet, and a salt water draft of 47 feet.

c. Commerce. Statistics on commerce of the Port of Philadelphia (Trenton, N. J. to the Sea) are listed in table S-1, which shows data for representative years from 1906 to 1958. Intra-harbor receipts and shipments are excluded from the table because most of this commerce is between points above the proposed barrier site and are not pertinent to consideration thereof. The table shows that commerce in the Delaware River port area amounted to 80,322,985 tons in 1958, and that the total commerce has increased steadily from 1920 to 1957, except during 1952 and 1953. The total commerce also declined slightly during calendar year 1958. Much of the 1958 decline is noted in the foreign export trade, which also showed a national decrease of about 30 percent in 1958.

S-02. WATER SUPPLY.

a. Existing Conditions. The existing saline condition of Delaware River below Philadelphia precludes it as a presently feasible source of potable water, although large quantities of brackish water are being withdrawn daily for industrial purposes. Fresh water for domestic, industrial, and irrigation purposes in the Delaware basin below Trenton is now being obtained from the Delaware above Philadelphia, from triburary streams, and from ground water sources.

b. Future Requirements. Future water demands of the metropolitan Philadelphia area of southeastern Pennsylvania can be met by further development of surface sources upstream from Philadelphia. Projected water requirements for southern New Jersey will doubtless be satisfied by additional withdrawal from ground water sources, augmented by presently planned surface sources from fresh water streams. However, the future fresh water situation in the State of Delaware is serious. The streams within the state are small and reservoir sites are scarce. Ground water supplies may become contaminated with saline water if attempts are made to meet the water demands of the growing population and the increasing industrial activity from these sources. Studies of the water supply problems of the State of Delaware have been made by state engineers and by the Corps of Engineers. Estimates of future water needs made by state engineers are based on a 30-day maximum, while estimates made by the Corps of Engineers are based on average use. The estimates are in close agreement, and are presented in Appendices O and P to this report. It was determined that a large portion of the gross water needs for the Wilmington area are capable of being satisfied from the brackish water of Delaware Bay. The analysis of the projected 30-day maximum fresh water needs indicates that by the year 2010, New Castle County, Delaware will require 567 million gallons per day. The available minimum flow of Christina River, which includes the Brandywine and White Clay Creeks, is 100 m.g.d. This quantity will satisfy all of the fresh water needs of the Wilmington area until 1976. The proposed Newark and Christiana reservoirs, described in paragraph 9-02, would provide augmentation amounting to 67 m.g.d., which would satisfy all

TABLE S-1

COMMERCE OF THE PORT OF PHILADELPHIA
(Trenton, N. J. to the Sea)

Year	Vessel Movements Foreign and Coastwise Trades Only	Commerce (Short Tons)			
		Foreign		Domestic (1)	
		Imports	Exports		Total
1906	10,967	1,732,935	3,800,995	(2)	
1910	12,378	2,948,179	2,532,677	(2)	
1920	8,350	3,808,768	7,575,008	4,956,765	16,340,541
1930	15,294	5,377,468	2,049,243	16,231,397	23,658,108
1940	16,842	5,890,927	2,278,052	25,979,764	34,148,743
1950	16,925	23,586,692	1,564,028	30,323,551	55,474,271
1951	17,635	22,243,510	5,634,546	32,466,201	60,344,257
1952	17,913	22,204,112	3,564,596	31,864,740	57,633,448
1953	18,200	25,550,577	1,696,194	32,730,828	59,977,599
1954	18,972	30,300,430	2,590,630	30,536,570	63,427,630
1955	19,157	36,150,777	3,610,961	30,354,679	70,116,417
1956	20,357	40,002,754	6,123,196	32,584,437	78,710,387
1957	20,092	41,344,163	6,225,081	37,158,020	84,727,264
1958	18,891	42,318,271	3,253,946	34,750,768	80,322,985

(1) Excludes intra harbor receipts and shipments.

(2) Not available due to use of different statistical classification prior to CY 1920.

the Wilmington area needs to the year 1986. The remaining 400 m.g.d. required by the year 2010 would have to be obtained from other sources. The 30-day maximum quantity of 400 m.g.d. is equivalent to an average water use of 273 m.g.d., as shown in Appendix P.

5-03. FISH AND WILDLIFE.

a. Fish. Delaware Bay presently supports one of the most productive commercial inshore fisheries along the Atlantic Coast. The bay directly produces 12,000,000 to 15,000,000 pounds of food stuffs annually, and contributes indirectly in maintaining certain oceanic fish stocks. For example, between 35 and 51 percent of the total annual catch of Atlantic menhaden comes from waters in the immediate vicinity of Delaware Bay. Many anadromous and catadromous fishes such as alewives, shad, striped bass, and eels presently migrate upstream and downstream through the lower sections of the river during stages of their life cycle.

b. Oysters. Oyster culture has been a large industry in Delaware Bay for many years. Delaware Bay oysters have long been known for the excellent white appearance of their meats and their fine condition. Seed beds are located in the river approximately 20 miles below the proposed barrier site. The beds extend downriver another 12 to 15 miles, and have an estimated 50,000 acres of oyster rocks. Growing beds are located off the mouth of Maurice River on the New Jersey side, and off Port Mahon on the Delaware side. In addition, another seed business has been developing along the Cape May shore of Delaware Bay. The industry has suffered recent heavy mortalities, shortage of seed, and heavy losses from pests or enemies, all of which have resulted in a sharp decline in oyster production. However, studies are being made to determine means of halting the losses and increasing the production.

c. Wildlife. The major wildlife resources of the Delaware River estuary are waterfowl, consisting of ducks, geese, brant, rails and coot; and fur-bearing animals, of which the muskrat is the most important. The tidal marshes along the river and bay provide habitat for both groups.

5-04. RECREATION. Recreational activities related to the water resources of the tidal reaches of Delaware River and Bay consist principally of boating, hunting, and fishing. Pleasure craft of all types and sizes are concentrated in large numbers at several locations where adequate facilities for service and storage have been developed. Nearly all of the tributary streams, particularly those with improved channels, are operating bases for a variety of recreational craft.

5-05. Sport fishing is a popular activity, particularly in the lower river and bay. Boats, bait, and equipment are available for hire at many locations along both the New Jersey and Delaware shores. The tidal and non-tidal reaches of tributary streams are also popular fishing areas, and yield many varieties of game fish.

5-06. FLOOD PROBLEMS. High flood stages in the tidal reaches of Delaware River and Bay usually develop from a combination of high tides and high upriver run-off. The effect of upriver run-off on river stages is generally significant only in the reaches above Philadelphia since the volume of river discharge is relatively small when compared to the volume of tidal flows in the lower sections of the river. The maximum flood of record upstream of Philadelphia occurred in August 1955 when a high rate of fresh water discharge and storm tide conditions produced extreme flood stages. [2/] The maximum stage of record at Philadelphia was produced by the storm of August 1933. From Marcus Hook downstream the maximum stages were produced by the storm of November 1950.

5-07. Floods in the tidal reaches have inundated low areas and caused damage to properties. There are many low-lying areas subject to tidal flooding along Delaware River and tributaries below Trenton. Some of these areas in the lower reaches, below Delaware Memorial Bridge, are sparsely developed and consist generally of marshland. However, some of the low-lying areas in the upper reaches are highly developed and industrialized. Many homes and business establishments in this latter area would be greatly affected by high tidal stages such as might be produced by tidal surges related to hurricanes. Preliminary analyses made in connection with studies of hurricane problems have indicated that storm surges which have been experienced in the Delaware estuary are in no way indicative of the magnitude of surge that could be expected under the most critical hurricane conditions. Damage from such an occurrence would be very great, especially in heavily populated areas. Hurricane surge tides could produce floods that would inundate large areas and affect major vital industries as well as residential areas, city streets, and arterial highways.

SECTION VI - IMPROVEMENT DESIRED

6-01. PUBLIC HEARING. A public hearing was held by the District Engineer at Wilmington, Delaware on 20 October 1958 for the purpose of obtaining authoritative information and views concerning the feasibility of constructing a barrier in the Delaware estuary. The hearing was attended by 276 representatives of the Federal, State and local Governments; officials of maritime, commercial and civic organizations, and of major industries of the area; and interested individuals of the locality. A digest of the record of the proceedings at the hearing is presented in Appendix A, to this report on the comprehensive survey, and the views expressed are summarized below.

2/ See Appendix D "Flood Damages."

6-02. VIEWS OF LOCAL INTERESTS. The State of Delaware presented testimony through various State agencies indicating that in the near future available fresh water supplies will not satisfy the demands of the State. Realizing the need for additional sources of fresh water, the State of Delaware has proposed the study of a barrier in the Delaware estuary to determine its potential as a possible fresh water source for the State's future needs.

6-03. Statements opposing the construction of the barrier were made by maritime, commercial and municipal interests located upstream of the suggested site, and by the oyster and fishing industry in the lower bay. The opposition expressed their concern for Delaware's need of a fresh water supply, but opposed a barrier due to the many detrimental effects such a structure would probably produce. The opponents expressed a hope that the study would disclose a more economical and desirable means of providing a fresh water supply for the State of Delaware. The organization opposing the barrier requested that, during the study of such a structure, their interests be carefully considered.

SECTION VII - MODEL STUDIES

7-01. Tests were made in the existing model of the Delaware River at the Waterways Experiment Station, Vicksburg, Mississippi, to determine the type of barrier that would effectively stop the intrusion of salt water. Details of the tests are presented in attachment 1. Two plans or types of barriers were tested at the same location in the model. Plan A consisted of a barrier with a navigation opening 500 feet wide at elevation - 40 feet, to permit the passage of vessels, and a spillway 4000 feet long with a crest elevation of + 6.0 feet for the passage of peak fresh water flows. Plan B, consisted of a barrier with four navigation locks, for the passage of vessels, and a spillway 4000 feet long with a crest elevation of + 8.0 feet, to prevent overtopping by the tides. The tests, though preliminary in nature, permitted determination of the type barrier required based on the following conclusions.

a. The barrier tested as Plan A, having an ungated opening, would have no beneficial effects on salinity upstream of the barrier site, because the upstream limit of salinity intrusion would not be reduced.

b. The barrier tested as Plan B would cause more extensive salinity intrusion than now occurs unless means were provided for removing the salt water which would enter the upper pool during each ship transit through the locks.

c. Modifying Plan B, the barrier with locks, by providing a sump and drain system would probably effectively control salinity above the barrier, but it appears that pollution of this pool by municipal and industrial wastes would be greater than now occurs in that portion of the river because of elimination of tidal circulation.

d. Any barrier in the estuary which would afford an appreciable obstruction to the tidal wave would cause drastic changes in the tidal regimen. The maximum change would be caused by a navigation-lock type of barrier, as illustrated by the effects of Plan B. In reaches where the low-water plane would be lowered, compensatory dredging would be required to maintain the necessary navigable depth at mean low water.

SECTION VIII - PLAN OF IMPROVEMENT

8-01. BARRIER

a. Description. The proposed plan for providing a salt water barrier and a source of fresh water that could be developed for domestic and industrial use in New Castle County, Delaware, is to construct a dam across the Delaware River a short distance below the town of New Castle, Delaware. The proposed dam will be constructed to a top elevation of +28 feet Delaware River datum, with a top width sufficient to accommodate an access roadway, and will consist of the following five principal parts or sections: levee, across the land areas; earth embankment, in part of the river; locks, for navigation; a concrete gravity spillway section; and a concrete gravity non-overflow section, for transition between the spillway and lock section. It may also be necessary to install a fish ladder in the structure. The complete barrier will be approximately 53,300 feet in length. The general plan of the proposed barrier is shown on plate S-2, and elevation and cross-sections are shown on plate S-3. Details of the five principal sections and a discussion of the proposed fish ladder are presented in the following sub-paragraphs.

(1) Levee sections will be built across the land area and marshes requiring diking. The levees will be constructed of semi-impervious fill, and have side slopes of 1 on three. Rip-rap will be placed on both sides of the levee sections.

(2) The embankment sections are comprised of earth fill placed in the shallower portions of the river near the shores by hydraulic fill. The side slopes will be 1 on 5 and rip-rap will be placed on both sides of the embankment.

(3) The spillway is a concrete gravity section 4,705 feet in length, a crest elevation of + 6 feet Delaware River datum, and equipped with vertical lift crest gates to provide a closure of 28 foot elevation. Two gantry cranes are provided to lift and lock the gates in open position. This section will require support from steel H piling.

(4) A non-overflow concrete gravity section 620 feet long will provide a transition between the lock section and spillway.

(5) The lock section will contain 4 locks located symetrically about a center island or esplanade, on which will be the control tower, administration building and maintenance shops. On each side of the center island will be located the two large locks, with the two small locks located near the ends of this section. This section will also require support from steel H piping.

(6) The Fish and Wildlife Service has indicated that a fish ladder will probably be required if a complete or solid barrier is constructed across the Delaware estuary. The scope of this study precludes detailed estimates of type, size or cost of a fish ladder. However, the contingency allowance which has been included in the total estimated cost of the barrier will adequately cover the cost of a fish ladder.

b. Basis of Design. The following considerations and criteria influenced and determined the design of the barrier.

(1) The model test made to determine the type of barrier that would effectively stop the intrusion of salt water indicated that a barrier with an ungated opening would increase the salinity concentration above it, and that a gated structure would be required to effectively control the salinity. Therefore, a dam with a controlled spillway section, and locks to accommodate navigation was proposed.

(2) Navigation on the Delaware River to and from the Philadelphia Port area requires the installation of locks as part of the barrier structure. The vessel traffic on the river is heavy and is comprised of a wide range of ship classes, which include the largest type bulk carriers and naval vessels afloat. It is considered that the large volume of vessel traffic and wide range of vessel sizes will require the installation of four locks, two large locks each capable of handling the largest vessels which frequent the Delaware and two smaller locks to accommodate the large volume of common class vessels transiting the river. The large locks will be 1200 feet long and 170 feet wide, and will provide a depth of 50 feet over their sills. The smaller locks will be 500 feet long and 80 feet wide, and will provide a depth of 35 feet over the sills.

The barrier must be constructed to an elevation that will prevent overtopping by storm tides which would contaminate the fresh water pool above the dam and render it temporarily unsuitable for water supply. The factors considered in establishing the top elevation of the barrier were (1) a maximum hurricane surge occurring at the time of normal high water, and (2) an allowance for probable wave height and runup that would occur from the maximum wind velocity accompanying extreme hurricanes. The maximum hurricane surge was determined to be 13 feet. Normal high water

at the barrier is 6 feet, referred to Delaware River datum. The probable wave height and runup, that would occur from maximum wind velocity accompanying extreme hurricanes is 9 feet. Summation of the above figures indicates that the maximum elevation the water on the downstream side of the barrier could reach is 28 feet (Delaware River datum).

There is no record of any experienced stages of this magnitude in the Delaware estuary. It is therefore, considered that a barrier with a top elevation of 28 feet would be adequate and provide sufficient freeboard for all but the most extreme and infrequent conditions. To prevent flanking the dam must extend to high ground, on each side of the river, equal in elevation to that required for the dam. These criteria establishes the length of the barrier, and requires an extensive section of levee on the New Jersey side of the river.

(3) The elevation of the fresh water pool above the barrier will be dependent upon the elevation of the spillway crest, and established with respect to existing waterfront structures, and drainage facilities. It is proposed to establish a constant water level at approximately the plane of present mean high water.

(4) Construction materials are available within reasonable hauling distances from each terminus of the proposed dam. Within a three mile radius of the ends of the dam, hills rising to a maximum elevation of 80 feet are composed of gravels, sands, silts, clay and at lowest elevations silty sand with clay and marl, capable of being used in the earth fill portions of the barrier. Granular materials for embankment construction can be obtained and placed by hydraulic dredging from the river bottom and lands adjoining the river. Revetment stone can be obtained from the Trenton locality (65 miles) or Port Deposit (30 miles).

8-02. RELOCATION AND DRAINAGE. Construction of the barrier will require some relatively minor road relocations. All roads except those being abandoned will be routed over the levee, with maximum grades of 3 percent. The relocated roads will structurally conform to applicable state requirements. Major streams will be relocated as required and carried through the levee either by culverts or conduits equipped with tide gates. No major relocations of streams are contemplated. Interior drainage of a relatively minor nature will be taken care of by miscellaneous drainage ditches.

8-03. ANCHORAGES. In order to accommodate vessels required to wait transit through the locks. The proposed anchorage areas will be trapezoidal in shape, approximately 12,000 feet in length along the channel, tapering to 6,000 feet along the land side, and having a maximum width of 3,000 feet and will accommodate 3 ships, 1000 feet in length. The anchorage below the barrier will be located on the New Jersey side of

the ship channel about 5 miles downstream of the barrier, and the anchorage above the barrier will be located on the Delaware side of the ship channel about 2 and 1/3 miles upstream of the barrier. The locations of the proposed anchorage are shown on plate S-1.

8-04. CHANNEL. The elevation of mean low water will be lowered downstream of the barrier. As the authorized depth of a ship channel improved by a Federal project is measured from the plane of mean low water, any change in the elevation of mean low water will require new work dredging to reestablish the authorized depth.

8-05. SCAVENGER SUMP. The model tests made of the proposed barrier showed that the lockage of ships through the barrier would allow salt water to enter the upper pool in such quantity as to destroy its value as a source of fresh water. It is therefore, necessary to install a salt water scavenger pump to collect the intruding salt water. The proposed sump is to be 2,000 feet long, 800 feet wide, with a bottom elevation of -50 feet, and located on the channel center line about 5,000 feet upstream from the barrier. A gravity drain from the bottom of the sump will carry the collected salt water downstream from the barrier. The gravity drain will pass an average discharge of 2,000 cubic feet per second.

8-06. WATER SUPPLY.

a. General. The plan for taking water from behind the proposed barrier was developed from the investigation of two locations for the intakes, and a determination of the types of conduit required to transmit the water from each of the locations. The water supply from an intake at either location would be pumped to a common point, the Edgar M. Hoopes Reservoir located northwest of Wilmington, for storage and dispersion. This Reservoir was chosen as a basis for comparative cost estimates and is not necessarily the point to be used if the plan is adopted. Based on preliminary estimates of water requirements, the design capacity of the water supply facilities is 525 mgd. More detailed estimates have shown that the requirements would actually be 567 mgd, at year 2010, of which 100 mgd would be supplied from Christina River surface flows. The remaining 467 mgd would be obtained from the barrier pool. It was not considered necessary for the purposes of this investigation, to redesign the facilities to provide 467 mgd in lieu of 525 mgd. The small reduction in pumping costs would have little effect on the annual charges used in the economic analysis. Furthermore, detailed studies beyond the scope of this investigation would be required to size the facilities with consideration given to needs after year 2010.

b. Intake. The location of the two points of intake investigated are: (a) in the vicinity of Edgemoor, Delaware, about the closest point in the Delaware River to Hoopes Reservoir, and (b) in the vicinity of New Castle, Delaware, near the proposed barrier. The two locations,

which are indicated on plate S-2, were selected for investigation because they offered available undeveloped river frontage of sufficient size to accommodate the required intake structure without extensive relocation of any existing facilities and it is not anticipated that pollution will be excessive in these areas. For the purpose of this study only the basic features of an intake were considered. These consist of a structure containing the following: trash rack and boom, rake gantry, traveling water screens, sluice gates, pumps, motor driver, transformers, switch gear, control panel, plumbing and heating and ventilating equipment. The pumps and equipment will be the same for an intake at either location. Installation of fourteen 40 mgd capacity pumps will be required to meet the design capacity estimated at 525 mgd and allow one pump to act as a standby. The intake structure will be similar for either location, the only difference being modifications of foundations and substructure for site adaptation. The estimated costs for the intake at the two possible locations are very nearly the same, and selection of the locations must be based on the cost of transmission facilities.

c. Transmission lines. It has been determined that a transmission line 13 feet in diameter would be required to meet the hydraulic conditions involved in pumping 525 mgd of water. Two possible methods of constructing the transmission line were considered for each of the intake locations: (a) reinforced concrete pressure conduit, placed approximately 20 feet below the surface of ground, and (b) concrete lined pressure tunnel, through rock where construction by hard rock mining methods could be accomplished.

(1) The transmission line from an intake located at Edgemoor to Hoopes Reservoir would traverse the densely developed area just north of Wilmington. Due to the density of development in this area, construction of a 13-foot diameter reinforced concrete conduit, placed approximately 20 feet below the surface of the ground by open excavation, would disrupt the area and incur extensive right-of-way costs. Therefore, construction of the transmission line by tunneling is considered to be more practical. Construction of a pressure tunnel by hard rock mining methods is feasible at this location since Edgemoor is located near the edge of the Piedmont Plateau, which is characteristically underlain with crystalline rock that lends itself to tunnel construction. This transmission line would consist of approximately 39,000 feet of concrete lined pressure tunnel 13 feet in diameter constructed at an average depth of about 400 feet below ground level. The route of the proposed tunnel is shown on plate S-3.

(2) The intake located in the vicinity of New Castle, Delaware is farther from the Hoopes Reservoir than the Edgemoor location, but the required transmission line would pass through a less densely developed area. The method of constructing the transmission line could therefore be by open trench excavation to accommodate a

reinforced concrete pressure conduit, 13 feet in diameter placed approximately 20 to 35 feet below the surface of the ground. This proposed line would traverse, for the most part, the Coastal Plain through which tunnel construction would not be practical. The proposed route shown on plate S-3, will require approximately 60,000 feet of reinforced concrete pipe 13 feet in diameter.

SECTION IX - ALTERNATE PLANS

9-01. GENERAL. Investigations were made to determine alternate sources and methods of obtaining a fresh water supply capable of meeting the estimated future needs of northern Delaware. Estimates are based on a design criteria of 525 million gallons per day for the area by the year 2010. Alternate plans which would satisfy this requirement are discussed in the following paragraphs.

9-02. RESERVOIRS. Two reservoir sites in northern Delaware could be developed to produce a combined total of 67 million gallons per day. These reservoirs, which are discussed at length in Appendix Q, would be located on White Clay Creek and on Christina River. Their locations are shown on plate S-4. The reservoir located on White Clay Creek is referred to as the "Newark" reservoir and, when developed, will have a dependable supply of 42 mgd. The reservoir located on Christina River is referred to as the "Christiana" Reservoir and, when developed, will have a dependable supply of 25 mgd. The combined supply from the two reservoirs could be pumped to the Edgar M. Hoopes Reservoir, located northwest of Wilmington, for dispersion. This point was chosen for comparison of cost estimates and is not necessarily the place to be used if the plan is adopted. Hydraulic conditions require installation of three 18 mgd capacity pumps at Newark Reservoir and three 12 mgd capacity pumps at Christiana Reservoir. The pipeline system would consist of a 54-inch diameter reinforced concrete pressure pipe 33,200 feet long from the Newark Reservoir, and a 42-inch diameter reinforced concrete pressure pipe 33,700 feet long from the Christiana Reservoir, which would join and flow into a 66-inch diameter reinforced concrete pipe 18,500 feet long from the junction to the Hoopes Reservoir. The proposed routes of these pipelines are shown on plate S-4.

9-03. OTHER SOURCES. As the demand for water increases, utilizing and then exceeding the 167 mgd supplied by these two reservoirs, and available minimum flows it is proposed to obtain the additional quantity required from the Susquehanna River or Delaware River above the zone of salt water intrusion. Based on the estimated need of 567 mgd for the year 2010, the additional supply would be required to produce 400 mgd. (30 day maximum). Based on preliminary estimates, the design criteria used was 438 mgd.

a. <u>Susquehanna River</u>. The most feasible location for diversion from the Susquehanna River is at a point upstream from the Conowingo Dam, a hydro-electric power generating installation constructed by a subsidiary of the Philadelphia Electric Company. The Conowingo Dam is located approximately 10 miles above the mouth of the Susquehanna River at Havre deGrace, Maryland. Field reconnaissance indicates that a suitable location for an intake would be within the first 2,500 feet north of the dam on the east shore of the reservoir. Water on the upstream side of the Conowingo Dam is considered to be of excellent quality for utilization as a municipal or industrial supply. The intake facilities required are of a general type and similar to, but smaller than those needed for the sites investigated on the Delaware River discussed in paragraph 8-06b, because of the smaller quantity to be supplied. The required pumping capacity can be met by installation of twelve 40 mgd capacity pumps, with one pump as a standby. A transmission line from an intake on the Susquehanna River to the Hoopes Reservoir could be constructed by mining methods to produce a concrete lined pressure tunnel or by open trench excavation for a reinforced concrete pressure conduit. The route chosen for transmission by the pressure conduit takes advantage of the terrain and available gravity flow to keep pumping costs to a minimum. This route would require approximately 179,000 linear feet of 13-foot diameter reinforced concrete pressure pipe. A pressure tunnel would require approximately 160,000 feet of 13-foot diameter concrete lined pressure tunnel, six intermediate and dewatering shafts, plus two vertical shafts for intake and discharge from the tunnel. The pumping heads that must be developed to transmit the water from the Susquehanna source are dependent upon the method of transmission, being nearly twice as great for the pressure conduit as for the pressure tunnel. The location of the intake and the proposed alignment of the two transmission systems are shown on plate S-4.

Water obtained from the Susquehanna River above the Conowingo Dam will involve problems beyond the scope of this study, such as the legality of diverting water from its natural watershed, and the position the Philadelphia Electric Company takes in regard to the drawdown of its power reservoir. In view of the possible effects of these factors other sources of obtaining the required water were investigated and preliminary plans developed.

b. <u>Delaware River</u>. The additional supply required to augment the flow from the Newark and Christiana Reservoirs could be obtained from the Delaware River above the zone of objectionable salinity. It was considered that an intake location which could provide a supply with chloride content not exceeding 150 to 200 ppm more than one day a year would be suitable. Data obtained from chloride concentration determinations made over a period of about 18 years at five points along the Delaware River from Chester, Pennsylvania to northeast Philadelphia show that the salinity conditions exceeding these criteria extend upstream as far as Kaighn Point, Camden, N. J.

(1) South Street. Field reconnaissance of the river front in the vicinity of Kaighn Point indicated a possible site for an intake and pumping station at the foot of South Street in Philadelphia. At this location a chloride concentration of 175 ppm might be expected one day a year. Although this location is in a reach of the river that is carrying a heavy load of treated sewage and industrial waste high in coliform count, the quality of water which is available is no worse than would be obtained from the barrier pool. The intake and pumping capacity which would be required at the South Street location are similar to those of the intake proposed for the Susquehanna River described in paragraph 9-03a. Transmission of the supply from this source by means of a pressure pipeline of the size required would be impractical in view of the right-of-way required and the disruption of utilities in the densely developed area it must traverse. Therefore, it is proposed to transmit the water by a pressure tunnel. The construction would entail about 145,000 linear feet of 13-foot diameter concrete lined pressure tunnel through crystalline rock which underlies the proposed route. The location of the proposed route is shown on plate S-5. The total head against which the pumps must operate was calculated, and is reflected in the power requirements and operating costs.

(2) Poquessing Creek. Because of the low quality of water presently available at the South Street location, an alternate point of intake on the Delaware River was investigated. The alternate point is located between the City of Philadelphia's water filtration plant at Torresdale and the mouth of the Poquessing Creek. At this location a good quality of water with respect to salinity and pollution could be obtained. The facilities required for pumping and intake are the same as those required at the South Street location, except for the head requirement for pumping and the access requirement. The transmission facilities required would be a concrete lined pressure tunnel, similar to that required for the South Street location, except that from this location the proposed route will require approximately 203,000 feet of concrete lined pressure tunnel. The proposed location of the intake and route of the transmission tunnel are shown on plate S-5. It should be noted that the last nine miles of this tunnel route coincide with the proposed tunnel route from the South Street location.

SECTION X - PHYSICAL EFFECTS OF THE BARRIER

10-01. GENERAL. Constructing a dam in the Delaware estuary to stop the intrusion of salt water will produce various and far reaching effects on existing physical characteristics. Many of these physical effects will produce economic effects which are discussed in Section XIII.

10-02 SALINITY. The primary purpose of the proposed dam is to act as a barrier to the intrusion of salt water, and thus establish a source of fresh water supply in the Delaware River downstream of Philadelphia. Model tests of the proposed barrier, which are discussed in detail in attachment 1, have indicated that the structure and appurtenant sumps and drains would probably effectively control intrusion of sea water into the upper pool.

10-03. TIDES. The barrier will affect the tidal action of the Delaware estuary, eliminating the tide above the dam and changing the magnitude and timing of the tides below the dam. Eliminating the tide above the barrier will also eliminate the currents developed from the rise and fall of the tides in this reach of the river.

10-04. The model tests made to determine the effects of a barrier indicated that drastic changes in the tidal regimen below the barrier would occur. The tests show that the range of tide just downstream from the barrier would be increased by about 3.8 feet, and the times of high and low tide would be advanced by about one hour. Measurements of tidal heights made in the model immediately below the dam site indicate that the elevation of low tide would be lowered by about 2 feet, and the elevation of high tide increased by about 1.8 feet. The elevation of low water would be about 1.5 feet below Delaware River datum, and the elevation of high water would be about 8 feet above the same datum. The tidal current velocities would be reduced at all stations below the barrier, thus indicating that the tidal prism would be reduced appreciably.

10-05. WATER LEVEL. The proposed barrier will, in addition to stopping salt water intrusion and tidal action, produce a stabilized water level in the pool upstream from the dam. The elevation of the surface will be dependent on the spillway crest elevation, and is proposed to be established at about the present plane of mean high water. During freshets or floods in the Delaware the stage will be higher than the present mean high water, but not in excess of flood heights already experienced.

10-06. The established constant pool level above the barrier will stabilize the shore line, eliminating the tidal marshes and mud flats, and affecting many shore structures, storm drains, and sewage systems. Vertical clearances under bridges will be limited to the clearance now existing at mean high water. The additional depth of water available at all times will, in effect, provide deeper navigation channels in the tidal reaches of the Delaware and its tributaries above the barrier. The economic impact of these effects are discussed in Section XIII.

10-07 **OTHER PHYSICAL EFFECTS.** In addition to the above, many other changes in the physical characteristics of the estuary will result. A few of the more prominent physical characteristics that are expected to change are discussed in the following subparagraphs.

a. The effect of eliminating tidal currents on shoaling rates in the navigation channels was not investigated in detail. The establishment of a predominant, but weak, current in one direction above the barrier will doubtless affect shoaling rates and the locations where shoaling occurs. The average velocity of the current above the barrier will be much less than that occurring with the tidal cycle. This effect is expected to cause the streams involved to deposit their load of sediment near their confluence with the pool and the main stem, and for the sediment to remain near where it has been deposited. As shown in the model tests, tidal current velocities below the barrier will be reduced indicating that the tidal prism will be reduced appreciably. Reducing the velocity of tidal currents is expected to affect shoaling in the navigation channel, because reduced current velocities will affect the sediment carrying capacity of a stream. The navigation channel in Delaware Bay has required little maintenance, but with a barrier at New Castle, the shoaling rate might increase and cause a serious maintenance problem. No detailed study was made of the anticipated effect of reduced current velocities or shoaling below the barrier, but these factors would have to be carefully evaluated before construction.

b. The constant high water pool created behind the barrier will raise the ground water tables on both sides of the river. The extent, magnitude, and effect of this change have not been determined in these preliminary investigations.

c. Tidal currents have a flushing effect changing the water and keeping the temperature of the water uniform as determined by the existing weather conditions. Stopping the tidal currents will eliminate the flushing action and the temperatures will be affected. It is expected that the temperatures in the reservoir will be higher than those found in the same section of river under present conditions. An increase in the average overall temperature could have detrimental effects on the septic action of the sewage being dumped into the reservoir and on industries that now use cooling water from the river.

d. The pool formed above the barrier would become highly polluted if the present amounts of domestic and industrial wastes are discharged into it. Attachment 4 to this Appendix presents the views of the Public Health Service concerning the quality of the water in the pool. It is stated that "tidal currents which normally carry in suspension silt, organic matter and sewage particles will no longer be available to dispense these materials. This could create higher concentration of pollutants in some areas."

e. The combination of the reduction in salinity, elimination of the rise and fall of the water surface and elimination of tidal currents above the barrier will produce conditions more favorable to the formation of ice on the river. These factors will be partially offset by the higher temperature of the water in the pool. The fresh water above the barrier will freeze at a higher temperature than the brackish water being displaced. Under present conditions the rise and fall of tide help break up ice formations and the tidal currents carry the ice out. The elimination of these fluctuations in the surface level will allow ice to freeze solidly and remain at the location where it formed. In addition, when ice does break up, its passage downstream will be blocked by the barrier. Below the barrier, the flood currents will pile floating ice against the structure.

SECTION XI - ESTIMATES OF FIRST COST

11-01. SALT WATER BARRIER. Estimates of probable first costs, of preliminary scope, were prepared as a basis for appraising the possibility of developing an economically favorable barrier project. Since the preliminary costs of all technically practical versions of salt water barriers, that could be studied within the geographic environs of the comprehensive survey, obviously exceeded the costs of alternative developments to satisfy the water needs of the Wilmington area, refined and detailed cost estimates of survey scope were not warranted and, accordingly, have not been undertaken as a feature of this investigation. The preliminary total first cost of the barrier including the required facilities to maintain navigation is estimated to be approximately $345,000,000. The items considered in making the estimate include land, relocations, the barrier, spillway, gates and related facilities, locks, and the cost of modifying and providing channels and canals as required. The estimates are based on January 1960 prices, and include an appropriate allowance for contingencies on the construction features considered. Also included in the estimate are the costs of engineering and design, supervision and administration. The above estimated cost does not include the cost of providing an intake and transmission system that would be required to obtain the water supply. Because of the scope of the cost estimates details are not presented herein, but are available in the file of the U.S. Army Engineer District, Philadelphia.

11-02. WATER SUPPLY. The estimated costs of constructing the facilities required to obtain the water supply from above the barrier are approximately $35,000,000 for a pressure pipe line with the intake located near New Castle and $45,000,000 for a pressure tunnel with the intake at Edgemoor, Delaware.

11-03. **ALTERNATE WATER SUPPLY.** The costs of the alternate methods of water supply investigated as part of this study were estimated on the same basis as the barrier and the required water supply facilities with that plan. The estimated costs of the alternate plans include all known major features required for the system.

11-04. SUMMARY. Estimates do not include projections to the proposed dates of construction or refinements relative to the phased provision of pumping capacities. The total first cost of obtaining the required water supply by constructing the barrier and taking the water from the pool formed above it are estimated to be about $380,000,000 with the intake located near New Castle, Delaware, and about $390,000,000 with the intake located at Edgemoor, Delaware. The total first costs of obtaining the required water supply by the alternate methods investigated including the Newark Reservoir and the Christiana Reservoir together with intakes, pumps and pressure mains to the existing Hoopes Reservoir from these reservoirs and from an intake at South Street in Philadelphia are estimated to be approximately $160,000,000; from an intake located near Poquessing Creek on the Delaware River, $200,000,000; from the Susquehanna River with a pressure tunnel $170,000,000; and from the Susquehanna with a pressure pipeline, $140,000,000.

SECTION XII - ESTIMATED ANNUAL CHARGES

12-01. SALT WATER BARRIER. The estimates of annual charges are based on the first cost plus an allowance for interest on the first cost during construction. An interest rate of 2½ percent is used for comparison of plans, since this investigation does not consider apportionment of costs between Federal and non-Federal interests. The annual charges are comprised of: interest at 2½ percent on the above amount, amortized over a 50-year economic life of the project at 2½ percent interest rate, and the estimated annual maintenance and operation costs including power and payroll charges. The estimated annual charges for the barrier, the navigation facilities required in conjunction with it and intake and transmission system for water supply places the total annual cost of obtaining water by this method at over $21,000,000 for either intake location. The alternate methods for taking water from the Delaware River without a barrier have estimated annual costs of about $9,000,000 and $11,000,000 for the South Street and Poquessing Creek locations respectively, including the annual cost of the Newark and Christiana Reservoirs and distribution system to the Hoopes Reservoir. The annual costs of taking water from the Susquehanna River, including the Newark and Christiana Reservoirs and the distribution system to Hoopes Reservoir, are estimated to be in the magnitude of $9,500,000, for the transmission by a pressure tunnel, and $9,300,000 for transmission by a pressure pipeline.

SECTION XIII - ECONOMIC EFFECTS OF THE BARRIER

13-01. WATER SUPPLY. This study of a barrier on the Delaware estuary is being made principally to determine the Delaware River's potential as a possible additional source of fresh water for the future needs of the State of Delaware. A barrier below New Castle would control the intrusion of sea water into the upper pool, and provide definite benefits for both present and potential users of Delaware River water as follows:

a. By reducing the salinity, it would improve the quality for many firms who now pump water from Delaware River for their industrial needs.

b. It would make a supply of fresh water available for the future demands of communities in the northern part of Delaware, the City of Philadelphia, and other communities.

13-02. A barrier in Delaware River could be both beneficial and detrimental to the well water supply. The raising of water levels in the Delaware River by a barrier would generally raise the groundwater level near the river. This may create some subdrainage problems. The decrease in salinity will tend to increase the quality of water from those wells that are presently receiving recharge from the river; however, unless the discharge of industrial and municipal wastes into the pool is reduced, the quality of the water may deteriorate. The change in chemical quality may have some adverse effects on well screens and pumping equipment. A detailed study would be required to determine the advantages or disadvantages to the various areas along the river by the changes in natural groundwater conditions caused by construction of the proposed barrier.

13-03. NAVIGATION. A barrier in the Delaware estuary would be both beneficial and detrimental to navigation above the dam as follows:

a. Benefits

(1) A constant pool level would (a) eliminate delays caused by deep-draft vessels awaiting high tide in order to get enough depth to bring the vessel into the port area, (b) allow deeper draft vessels to navigate on Delaware River tributaries at all times.

(2) A fresh water pool above the barrier would possibly be a deterrent to marine growth which is harmful to vessels, and would result in lower maintenance costs for removal of barnacles, and a corresponding longer life for ship bottoms.

b. Detriments

(1) The locks in the barrier would result in increased costs to navigation interests because: (a) Ships would experience delays awaiting passage through the locks. It is estimated that the cost of these delays would exceed $1,000,000 annually; (b) the size of ships would be limited to the size of the locks; and (c) the locks could be easily destroyed in time of war and endanger national security.

(2) The ship channel conditions would be altered by a barrier in Delaware River: (a) The model study showed that the mean low water would be lowered below the barrier, which would require additional dredging in this area to bring the channel in this section to project depth; (b) there would probably be a change in shoaling characteristics above the barrier because the movement of sediment by tidal currents would be eliminated. Sediment from tributaries would tend to accumulate at their mouths, and additional maintenance would be required in these areas. In order to obtain more definite shoaling data, this matter should be the subject of a further investigation.

(3) It is believed that interruption of the tidal currents by the barrier may cause serious shoaling in the navigation channel downstream of the barrier. Additional maintenance dredging may be required in the navigation channel in Delaware Bay.

(4) A barrier will raise the level of the water in the pool above the dam and thereby reduce the maximum clearance of bridges in this area. This reduction in vertical clearance would be of significance, particularly on Delaware River tributaries where at many locations the bridge clearance at mean high water is less than is required for the passage of the small craft using the waterways.

(5) Ice floes occur infrequently on Delaware River. However, ice floes have been experienced, and if they should occur with a barrier in the river, they would move more slowly in the constant level pool than with the tidal current, and possibly restrict the channel passage as they move downstream. It is also believed that ice would accumulate at the locks, both upstream and downstream of the barrier causing delays to vessels approaching and using the locks.

13-04. FISH AND WILDLIFE. Delaware Bay plays a major role in maintaining the prosperity of certain species of fish, such as shad, striped bass and menhaden. Construction of a barrier would have an impact on the environment upstream and downstream from the project. In the upstream area reservoir conditions would prevail, and fish passages would have to be provided in the barrier. In this area, water quality might be poorer than at present, but it could also result in improvements in the habitat for fresh water fishes because of the existence of the barrier.

13-05. The oyster industry operates in the Bay below the barrier site. It is difficult to determine whether changes brought about by a barrier would be beneficial or detrimental to the oyster industry which requires special conditions favorable to reproduction, setting, and growth of oysters. Wildlife resources would be affected by construction of a barrier. The Delaware River estuarine marshes are a favorite habitat for wildlife, both waterfowl and fur bearing animals. Indications point toward higher water levels, greater salt water intrusion, and a greater tidal range downstream from the barrier site. Higher water levels, from the wildlife viewpoint, might be beneficial. However, greater salt water intrusion and a greater tidal range would be unfavorable to wildlife.

13-06. The United States Department of the Interior, Fish and Wildlife Service believes that in order to analyze the project operation of the proposed barrier, it will be necessary to know far more than is known at present about the relationship between existing tides, currents, salinity, sediment, nutrients, and other factors and the flora and fauna of the estuary. The Service states that if a thorough investigation of a barrier for Delaware River is to be undertaken, detailed studies should be made by the Fish and Wildlife Service over a period of five years at a cost estimated to be $1,060,000. Details concerning the types of fish and wildlife studies which would be required are contained in attachment 3.

13-07. FLOOD DAMAGES

a. Benefits.

(1) Low areas along the tidal reaches of Delaware River and its tributaries suffer occasional damage from abnormal tides induced by storms. Although the magnitude of experienced flood damages which may be attributed directly to tidal flooding has not been great, storm tide conditions occur coincident with abnormal upland discharges, and thus contribute to some very damaging floods. Peak stages referred to Delaware River datum which have been experienced are 11.0 feet at New Castle, 11.7 feet at Philadelphia, 13.6 feet at Burlington, and 20.9 feet at Trenton. However, recent studies made in connection with a survey of hurricane problems in the Delaware estuary have indicated that abnormal tides which have been experienced are in no way indicative of the maximum surge heights which would be induced by the maximum probable hurricane. It has been determined that under the most critical conditions, with the surge occurring on top of mean high water, resultant stages referred to Delaware River datum would be 17.4 feet at the barrier site, 18.8 feet at Philadelphia, 20.0 feet at Burlington, and 21.4 feet at Trenton. Floods accompanying these stages would be extensive, and damages great, especially in the population centers. Large industrial areas would be flooded, and their loss of productivity would affect the economy of the entire region. Flood waters would reach thousands of homes and commercial establishments, and damages would doubtless amount to billions of dollars.

(2) The proposed barrier has been designed to prevent overtopping by hurricane surges, and will therefore prevent all tidal flooding in the area upstream from the barrier site. Benefits realized will be equal to the total damages now experienced from tidal flooding, plus damages from possible hurricane surges and damages to future developments.

b. Detriments.

(1) Flood conditions will be aggravated in many communities now depending on low tide periods for drainage of surface waters. These communities will require adequate facilities to alleviate this condition.

(2) The area below the barrier will experience higher tidal flood elevations and greater flood damages because of the increased range of tide. The model study has shown that high tide just below the barrier will be 1.8 feet higher than at present (see paragraph 10-04). Tidal flood heights will be correspondingly higher, and will aggravate conditions at such developed areas as Delaware City and Bay View Beach, Delaware, which are presently experiencing problems from tidal flooding. In addition modifications of extensive systems of dikes and sluice gates designed to drain tidal marshes, particularly on the New Jersey shore, would be required. Expensive alterations to existing storm and sanitary sewers would be required.

(3) The possible effect of higher ground water levels on flood conditions has been considered, but additional investigation would be required to evaluate the condition. Local interests in some localities claim that basement floors in many homes are constructed just above the present ground water level, and that any increase in the water level will result in flooded basements.

13-08. RECREATION. The proposed barrier would have some beneficial and some detrimental effects on recreation in the area. Scenic qualities along the river and tidal sections of the tributaries above the barrier would be improved by the elimination of the mud flats and general unsightly conditions resulting from tidal action. The large fresh water lake above the barrier would be attractive for pleasure boating, and substantial recreational benefits might be realized in this activity if the water quality is not depreciated. However, the necessity for locking all craft through the barrier would be a detriment for pleasure boats which now travel unobstructed upstream and downstream. The effects that the barrier would have on fish and wildlife, as discussed in paragraph 13-04, would also affect related recreational activities.

13-09. **POLLUTION**. As a result of the preliminary model tests described in attachment 1, it appears that pollution of the pool upstream of the barrier by municipal and industrial wastes would be much worse than pollution of that portion of the river under existing conditions. Extensive modifications of waste disposal facilities and systems will be required to effectively control pollution. The cost of these modifications must be considered as a detriment attributable to the barrier.

13-10. INDUSTRY AND MUNICIPAL.

a. Benefits.

(1) A barrier across Delaware River below New Castle would effectively reduce salt water intrusion into the pool upstream. This would be beneficial to some industries now utilizing river water either for processing or cooling purposes. Some of these industrial plants have equipment installed to treat the water and render it suitable for industrial use. Others use untreated river water during periods of low salinity, and purchase water from municipal or commercial water supply systems during periods of high salinity. Monetary benefits will be realized from the reduction in the cost of treating or obtaining the necessary water.

(2) Industries locating along Delaware River above the barrier site could realize substantial benefits from the constant-level, high water pool. The construction of water intakes will be simplified and their cost reduced. Industries providing their own ship handling facilities will benefit from less costly initial dredging because of the deeper water, and from simplified cargo handling because of the constant water level.

(3) The one-directional flow of the current will be beneficial to some industrial water users who now experience difficulty in locating water intakes and waste outlets to eliminate the problem of drawing-in their own waste products during certain periods of the tidal cycle.

b. Detriments

(1) The one-directional flow and constant current velocity will create problems for ship builders.

(a) Proper timing is required in the launching of the large modern ships. A successful launching must coincide with the time of slack tide or the last few moments of the incoming tidal current. Construction of a barrier would produce a constant downstream river flow. Ship builders claim that if this flow exceeds 3 knots they will be unable to launch ships because of the possibility of the ship swinging downstream and creating a hazard to their own facilities and neighboring industrial installations on both sides of the river.

(b) The establishment of a constant pool at high water level will have the effect of reducing the length of some shipways as much as 120 feet, which would limit their shipbuilding capacity.

(2) Many municipalities and industries have storm and sanitary sewer systems, water intakes and outlet pipes which are designed for the fluctuating heights of the tidal cycle. The pool level above the barrier, maintained at the elevation of existing high water, may require that expensive modifications be made to a large number of these facilities. Concern, relative to the effect of the pool on outlets and intakes, was expressed at the public hearing by communities and industries that would be affected.

(3) It is possible that water temperature will rise in the upper reaches of the pool, especially where industries take large quantities of water for cooling purposes and return warm water to the pool. Water in the pool will not be circulated as the river water is now by tidal action and, when heated by the sun, the temperature will rise and make condensing more difficult.

13-11. SUMMARY

A summary of the effects of the barrier is shown on table S-2.

SECTION XIV - PROPOSED LOCAL COOPERATION

14-01. The preliminary nature of this study precludes establishment of definite requirements of local cooperation. Should survey scope studies be made these requirements would be established on the basis of allocation of the cost of the project between the purposes which would be served, such as water supply, recreation and flood control, and apportionment of the allocated costs between Federal and non-Federal interests on the basis of criteria applicable to each purpose. Under the policy established by the Water Supply Act of 1958 the Federal government may participate and cooperate with States and local interests in developing water supplies in connection with Federal projects for purposes such as flood control, but primary responsibility for development of water supplies is considered to rest with the States and local interests.

TABLE S-2

SUMMARY OF EFFECTS OF BARRIER DAM

Aspects	Benefits	Detriments	Indeterminate
Water Supply	(1) Large supply of fresh water from Delaware River. (2) Improved quality of ground-water near the river.	(1) High Cost (2) Relatively poor quality of water in the pool.	(1) Higher ground water levels
Navigation	(1) Upstream from barrier: (a) eliminate delays of ships (b) deeper water (c) deterrent to marine growth	(1) Lockage delays (2) Limitation on size of ships (3) Increased range of tide downstream of barrier (4) Reduced maximum bridge clearances (5) Aggravated ice conditions	(1) Change in shoaling characteristics
Fish and Wildlife		(1) Restricted passage of fish upstream and down-stream	(1) Change in water quality (2) Greater range of tide downstream of barrier (3) Permanent flooding of tidal marshes upstream of barrier
Flood Control	(1) Complete protection from tidal flooding upstream of barrier	(1) Increased tidal flooding downstream of barrier (2) Aggravate storm drainage problem in low areas (3) Higher ground water levels	

SECTION XV - COORDINATION WITH OTHER AGENCIES

15-01. GENERAL. All known interested agencies were contacted prior to the public hearing and invited to express their views. Replies were received from nine Federal agencies, four of whom expressed no comment. The Soil Conservation Service and the U. S. Bureau of Public Roads believe that a barrier will have a very limited effect on their interests. The U. S. Geological Survey wishes to be kept informed of the physical features of the proposed barrier. The U. S. National Park Service expressed the opinion that a fresh water pool above the barrier would benefit boating and fishing, and improve the scenic qualities along Dealware River. Comments made by the Commandant, Fourth Naval District, relative to effects of a barrier on Naval activities located along Delaware River, are summarized in Appendix A. The U. S. Public Health Service expressed its interest in water resource projects, and its need to make further study of various items relating to water quality upstream and downstream of the proposed barrier. The Regional Engineer of the Public Health Service later submitted an outline of the features that would require further study by that agency, a copy of which is presented as attachment 4. Representatives of the United States Coast Guard attended the hearing but did not express their views.

15-02. U. S. FISH AND WILDLIFE SERVICE. The U. S. Fish and Wildlife Service presented its preliminary views relative to the proposed barrier at the public hearing. Subsequent to the hearing it prepared and presented more detailed views in a report dated 7 October 1959, a copy of which is presented as attachment 3.

SECTION XVI - DISCUSSION

16-01. GENERAL. The purpose of this study is to investigate the engineering, functional, and economic feasibility of constructing a salt water barrier in Delaware estuary below New Castle, Delaware, with a view to determining if justification exists for making more detailed studies of the proposed project. The saline condition of Delaware River below Philadelphia precludes its use as a source of fresh water for northern Delaware. The primary function of the proposed barrier would be to halt the intrusion of salt water, and thereby provide northern Delaware with a large fresh water reservoir at its door step. The engineering feasibility of constructing the barrier, as well as its ability to effectively halt the intrusion of salt water, have been verified. However, such a structure would have numerous and complex physical and economic effects on the estuary and the lower Delaware Valley.

16-02. NAVIGATION. One of the major considerations would be the effect upon navigation. Delaware River from Trenton to the sea is one of the most important and busy waterways in the nation, with approximately 11,000 large ocean-going vessels transiting the river in 1958. All vessel traffic would have to be locked through the barrier and the construction, operation, and maintenance of adequate facilities to accomplish this efficiently and with the minimum of delays to shipping comprise a

substantial portion of the cost of the barrier. The studies have indicated that the barrier would constitute an obstruction to the free movement of vessel traffic in the river and would delay shipping so that the cost to navigation interests with existing traffic would exceed $1,000,000 annually. It is possible that some port facilities may be relocated below the barrier, thus affecting the value of water front property above the barrier. Benefits will accrue from increasing the depth of water above the barrier, eliminating delays to vessels awaiting tide and providing deeper water in triburary and main stream channels. Also, the fresh water pool would be a deterrent to marine growth. The net effect would be detrimental.

16-03. FLOOD CONTROL. The proposed barrier would have a significant effect on flood damages in the estuary. Damages from tidal surges would be eliminated above the barrier and increased below the barrier. The elimination of damage above the barrier would be a significant benefit because the area affected includes an intense concentration of population and industry, whereas the increase in damages from tidal flooding below the barrier would be small because the area affected is largely undeveloped. Potential damage from a flood associated with the maximum probable hurricane surge is huge and the barrier would remove this threat, however, a flood even approaching this magnitude would be an extremely rare occurrence. Since the frequency of this flood is obviously very low, its prevention is of doubtful economic value.

16-04. FISH AND WILDLIFE. The barrier would effect drastic changes in the natural state of the estuary by eliminating tidal currents and salt water in the area above the barrier, and would restrict free passage of migratory fish in the river. The permanent flooding of tidal marshes, and the elimination of saline water from above the barrier would have some beneficial and some detrimental effects on wildlife. The U. S. Fish and Wildlife Service has indicated that extensive studies would be required to determine the net physical and economic effects.

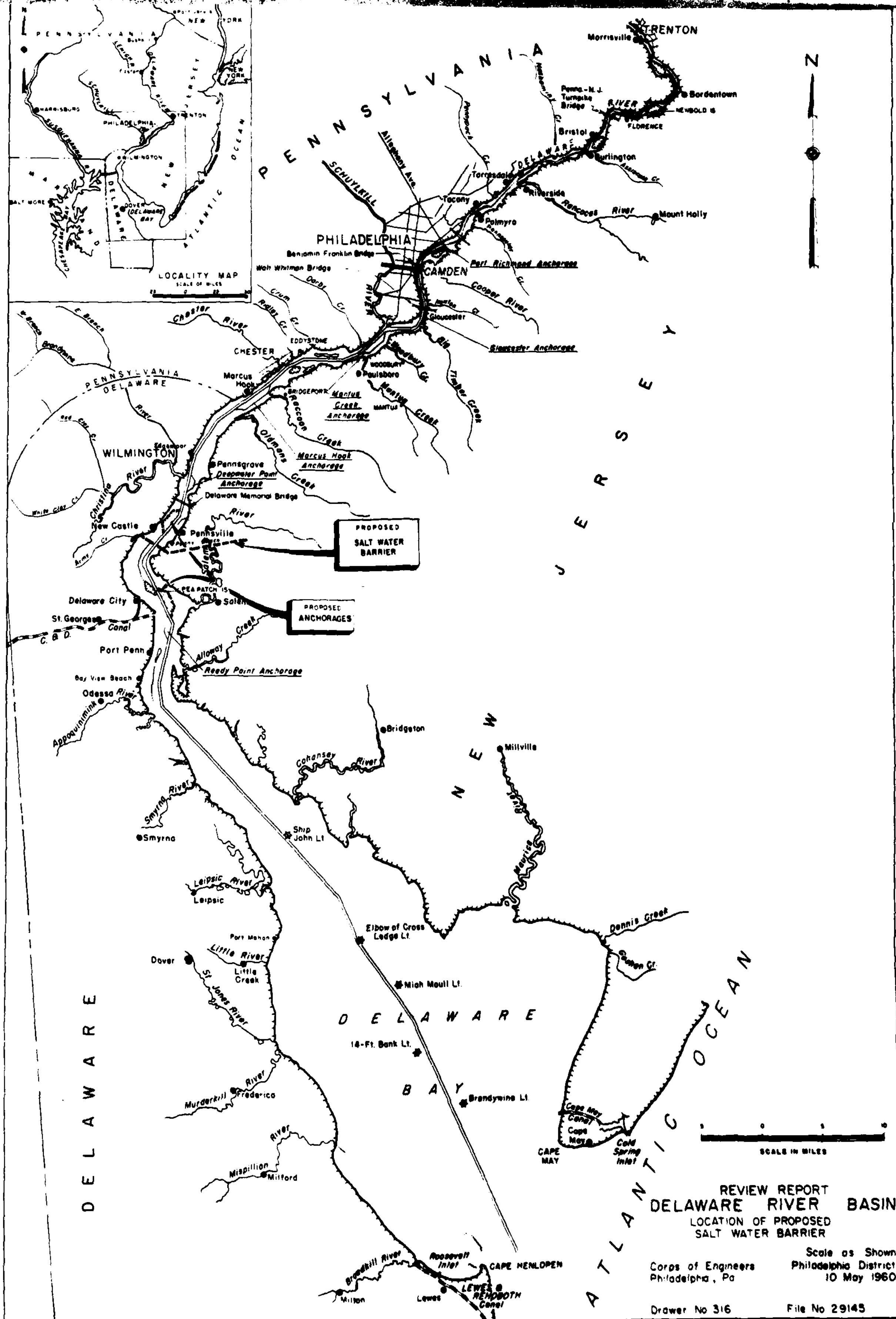
16-05. OTHER CONSIDERATIONS. In addition to the factors enumerated above, consideration must also be given to the many other economic, physical and social effects of the barrier. The creation of a large, fresh water lake above the barrier would directly or indirectly produce benefits as well as detriments to industry, recreation, transportation, national defense, and property values. No attempt has been made to place a monetary value on these factors, but it is considered that their total net tangible effect would not be nearly as significant as the effects upon water supply, navigation, flood control and fish and wildlife.

16-06. ECONOMIC ANALYSIS. It is a basic principle of project formulation that the project, as well as any separable segment or increment thereof selected to accomplish a given purpose, should be more economical than any other actual or potentially available means, public

or private, of accomplishing that purpose. The cost of making a product or service available by alternative means establishes a limit to the justified project investment for accomplishing any specific purpose. Since the primary function of the proposed barrier would be to provide a source of water supply for northern Delaware, investigations were made of the feasibility and cost of obtaining the required amount of water by alternate means. Alternate plans to provide the required 525 million gallons per day include the Newark and Christina reservoirs supplemented by a pressure tunnel to obtain water from an intake in Delaware River at Philadelphia or bringing water from the Susquehanna River by a pressure tunnel. The average annual charges for these plans are around $10,000,000. Water quality would probably be a determining factor in the selection of the best plan. The estimated average annual charges for the proposed barrier and appurtenant facilities are approximately $21,000,000, not including costs for modification to sewage and drainage systems. Consistent with the policy discussed above, in order for the project to be economic, the difference, which would be in excess of $11,000,000 annually, would have to be justified by benefits accruing to other purposes or functions. The principal considerations in this regard must be navigation, fish and wildlife, and flood control. Indications are that the net effect on the first two would probably be detrimental. Thus, it is evident that the barrier would be justified only if it can produce flood control benefits greatly in excess of $11,000,000 annually. Studies of hurricane problems of the Delaware estuary indicate that damages from tidal surges in the past have amounted to approximately $40,000 annually in the area between New Castle and Trenton. It is not likely that the addition of damages from a computed surge of low frequency would produce enough additional benefits to justify construction of the barrier. It is recognized that the State of Delaware has water problems which need to be solved, but they do not seem to justify so costly a remedy as a salt water barrier, especially when it is possible to obtain the water at much less cost by alternate methods without harmful effects to other important segments of the local economy.

SECTION XVII - CONCLUSIONS

17-01. The studies have shown that it would be feasible from an engineering standpoint to construct, operate, and maintain a barrier across Delaware River in the vicinity of New Castle, Delaware and that such a barrier would effectively halt the intrusion of salt water, creating a large fresh water lake which would provide a suitable source of water supply for northern Delaware. It has been further shown that the barrier would have complex and far-reaching physical and economic effects on water-supply, navigation, flood control, fish and wildlife, recreation, and industry. Consideration of all these factors does not disclose any clear-cut justification for making additional detailed studies of the proposed project at this time. It is estimated that studies of survey scope would take about 5 years to complete and would cost approximately $3,000,000. Work by other agencies at a cost of $1,500,000 is included in the above total.



REVIEW REPORT
DELAWARE RIVER BASIN
LOCATION OF PROPOSED
SALT WATER BARRIER

Scale as Shown

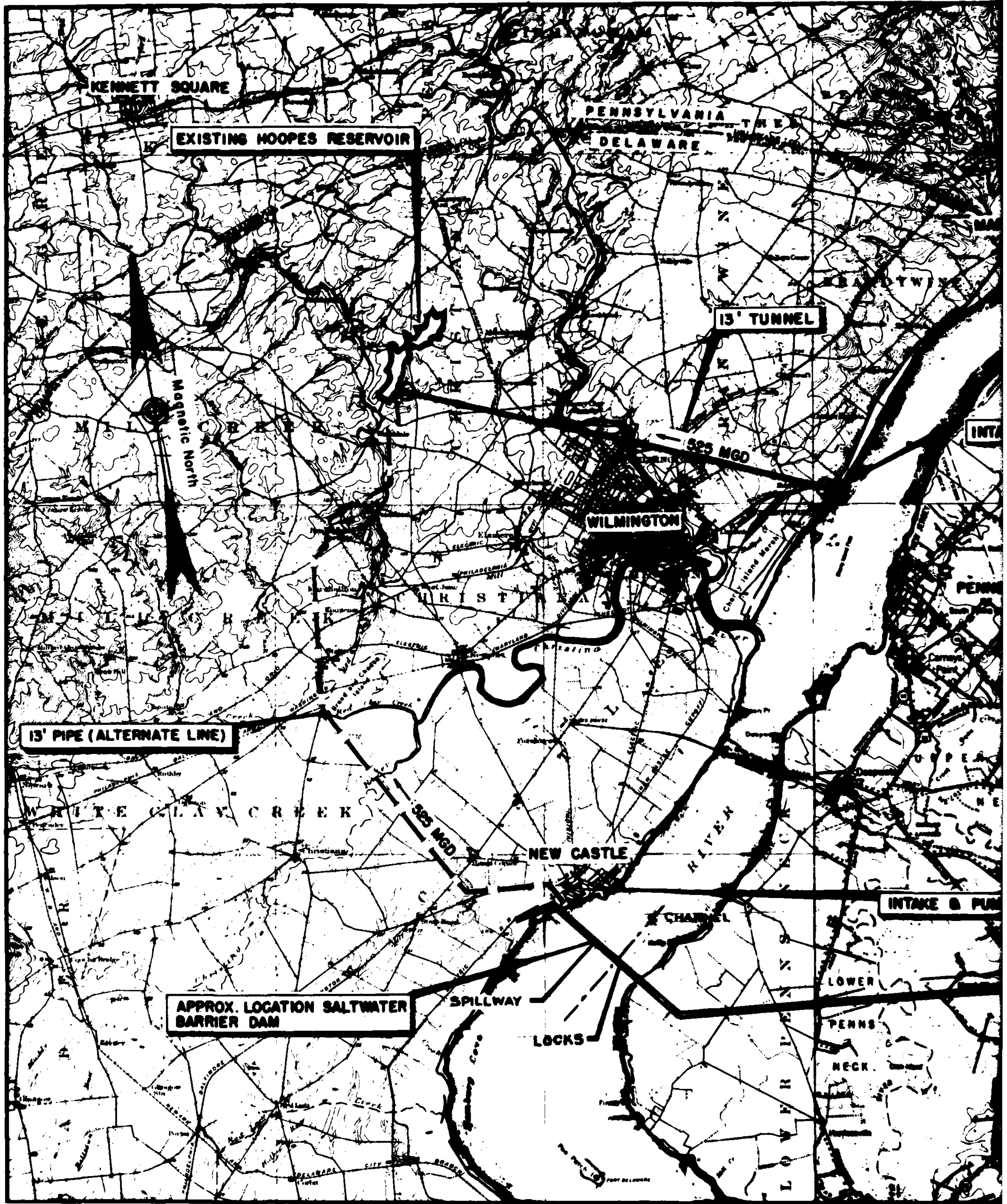
Corps of Engineers
Philadelphia, Pa

Philadelphia District
10 May 1960

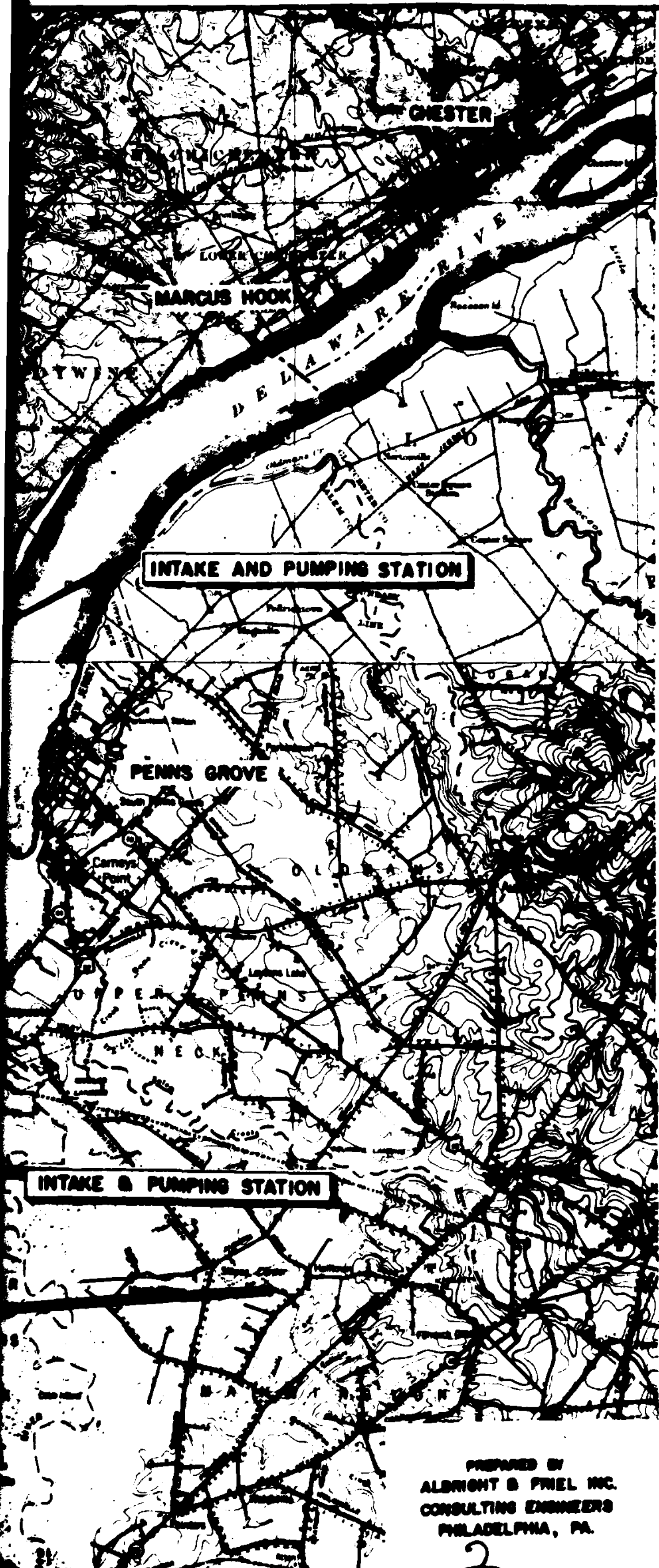
Drawer No 316

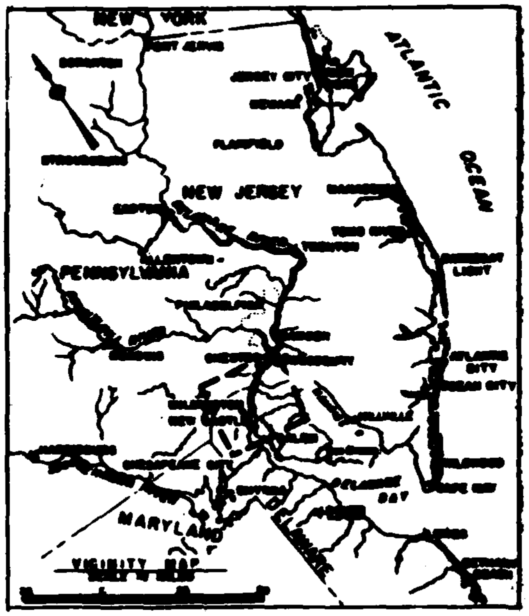
File No 29145

PLATE S-1



KENNETT SQUARE
EXISTING HOOPES RESERVOIR
PENNSYLVANIA
DELAWARE
13' TUNNEL
Magnetic North
525 MGD
WILMINGTON
CHRISTIANA
MILL CREEK
13' PIPE (ALTERNATE LINE)
WHITE CLAY CREEK
525 MGD
NEW CASTLE
RIVER
CHANNEL
APPROX. LOCATION SALTWATER BARRIER DAM
SPILLWAY
LOCKS
LOWER
PENNS
NECK





LEGEND

- VERTICAL SHAFT
- TUNNEL OR PIPELINE
- ALTERNATE LINE

SCALE IN MILES

1 0 1 2

REVIEW REPORT

DELAWARE RIVER BASIN

STUDY OF BARRIER DAM
WATER SUPPLY FACILITIES
WILMINGTON METROPOLITAN AREA
GENERAL PLAN

DATED 1 SEPTEMBER [illegible]

PREPARED BY
ALBRIGHT & FRIEL INC.
CONSULTING ENGINEERS
PHILADELPHIA, PA.

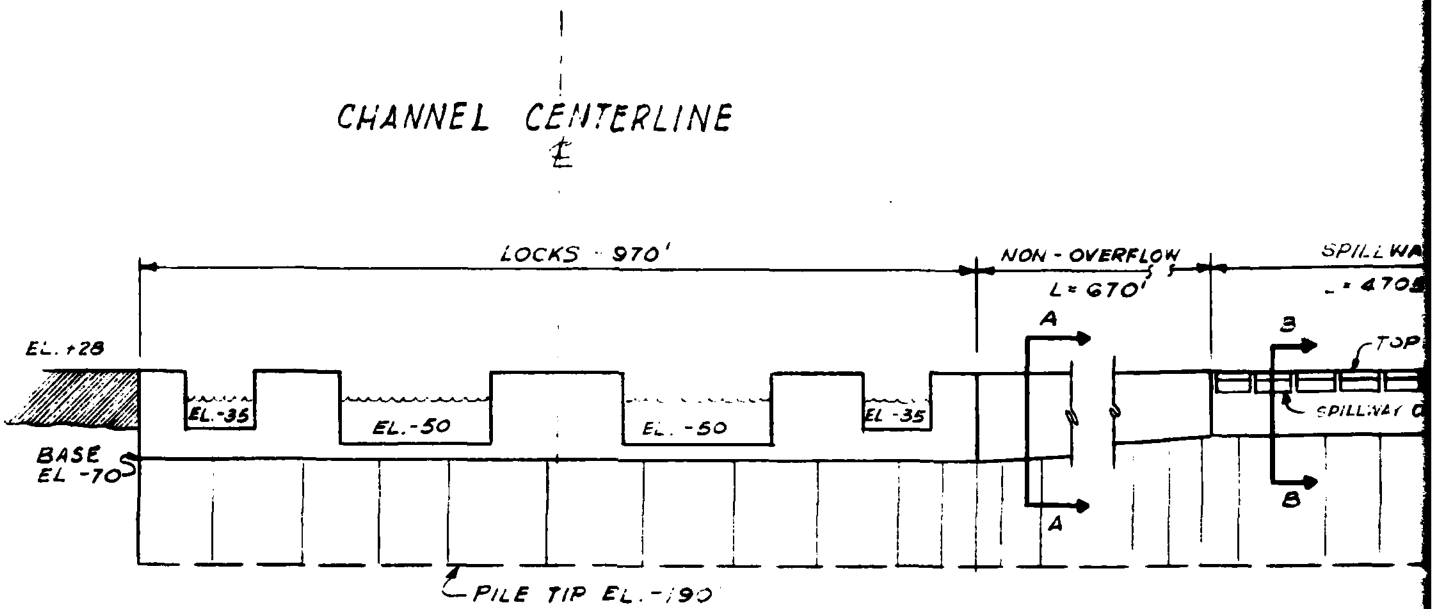
CORPS OF ENGINEERS
PHILADELPHIA, PA.

DRAWER NO. [illegible]

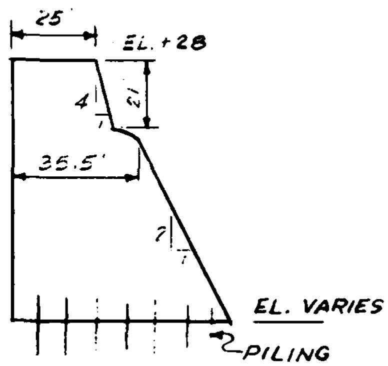
SCALE AS SHOWN
PHILADELPHIA DISTRICT
3 JULY [illegible]

FILE NO. [illegible]

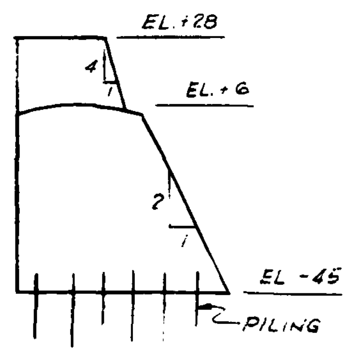
PLATE S-2



ELEVATION OF SPILLWAY & LOCKS
LOOKING DOWNSTREAM
SCALE: 1" = 50'

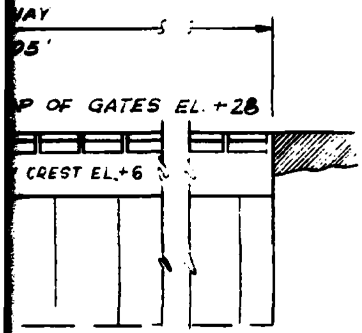


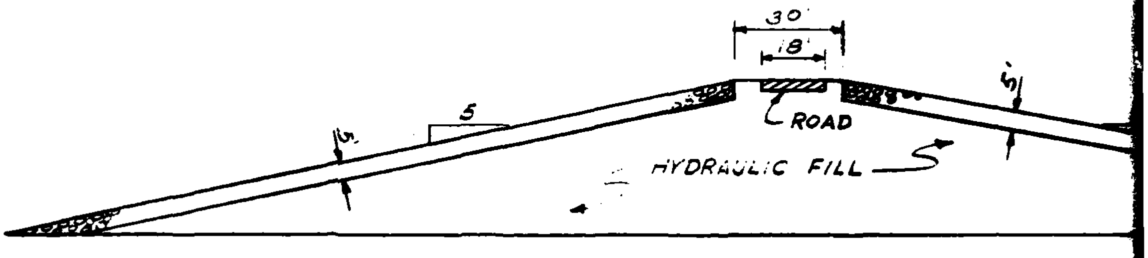
SECTION A-A
SCALE 1" = 50'



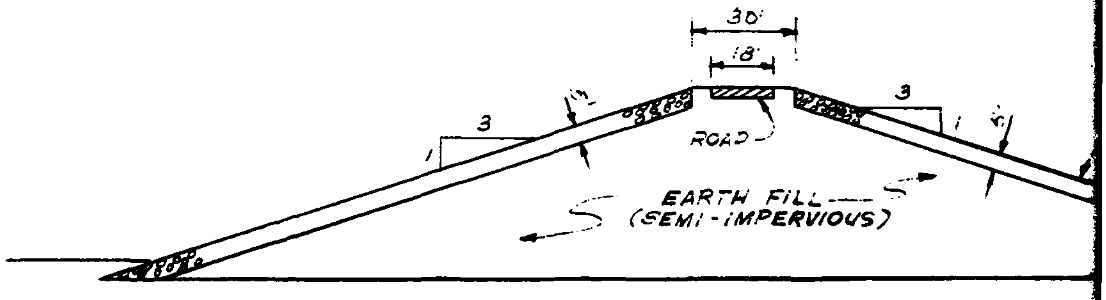
SECTION B-B
SCALE 1" = 50'

1





RIVER SECTION

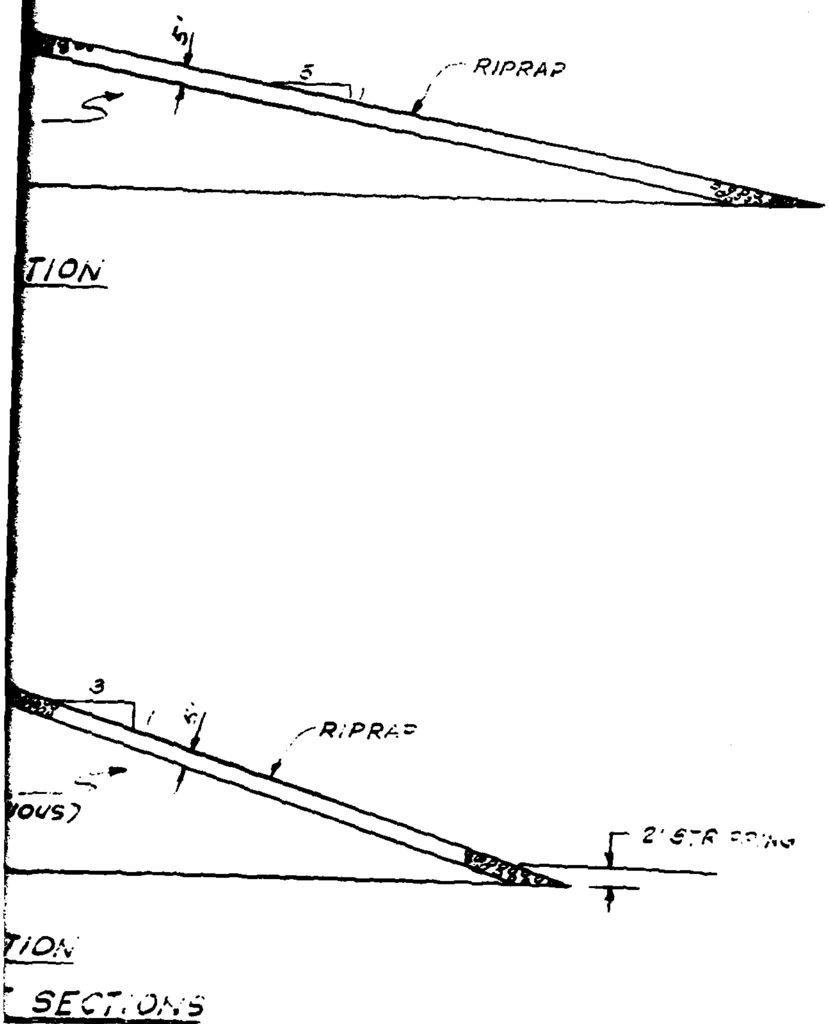


LAND SECTION

EMBANKMENT SECTIONS

SCALE 1"=50'

2



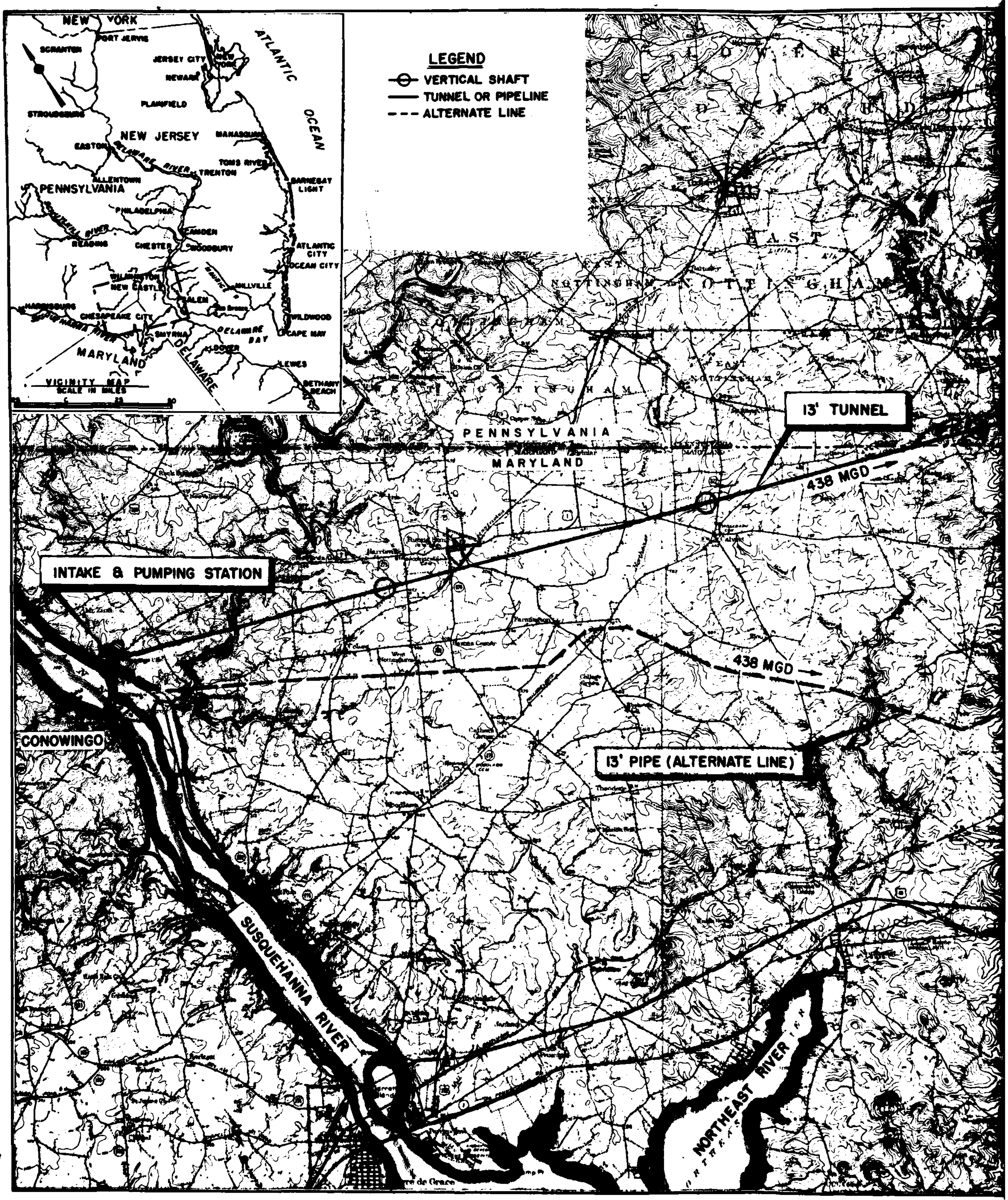
DELAWARE RIVER BASIN
BARRIER DAM STUDY

ELEVATION & CROSS SECTIONS

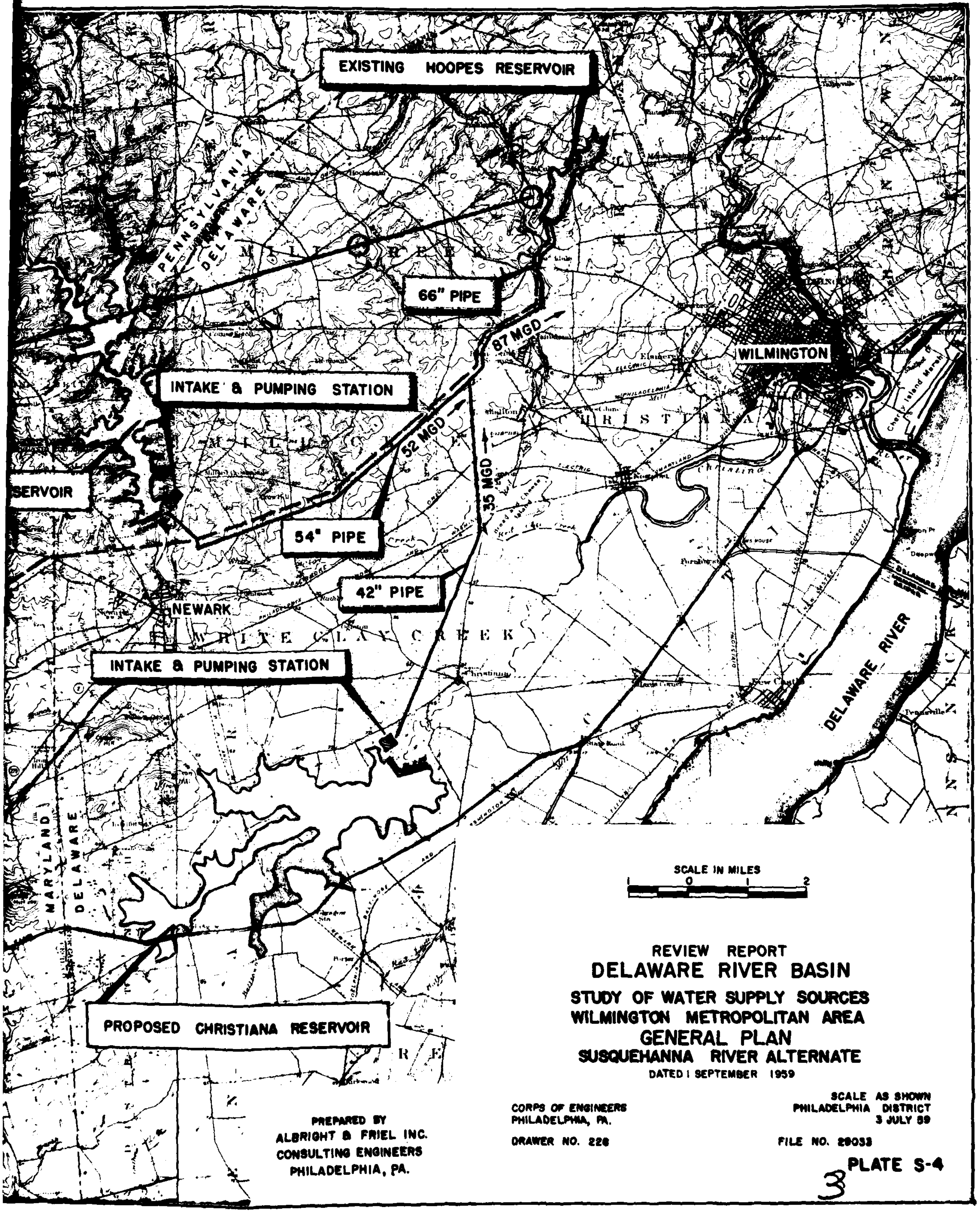
SCALE AS SHOWN

3

PLATE S-3


LEGEND
VERTICAL SHAFT
TUNNEL OR PIPELINE
ALTERNATE LINE
VICINITY MAP
SCALE IN MILES
NEW YORK
NEW JERSEY
PENNSYLVANIA
MARYLAND
DELAWARE
ATLANTIC OCEAN
13' TUNNEL
438 MGD
INTAKE & PUMPING STATION
CONOWINGO
13' PIPE (ALTERNATE LINE)
SUSQUEHANNA RIVER
NORTHEAST RIVER


EXISTING HOOPES RESERVOIR
Magnetic North
PENNSYLVANIA
DELAWARE
66" PIPE
87 MGD
INTAKE & PUMPING STATION
52 MGD
35 MGD
PROPOSED NEWARK RESERVOIR
54" PIPE
42" PIPE
NEWARK
WHITE CLAY CREEK
INTAKE & PUMPING STATION
MARYLAND
DELAWARE
ELKTON
PROPOSED CHRISTIANA RESERVOIR
ELK RIVER
REV
DELAWA
STUDY OF W
WILMINGTON
GEN
SUSQUEHAN
DATE
PREPARED BY
ALBRIGHT & FRIEL INC.
CONSULTING ENGINEERS
PHILADELPHIA, PA.
CORPS OF ENGINEERS
PHILADELPHIA, PA.
DRAWER NO. 228



REVIEW REPORT
DELAWARE RIVER BASIN
STUDY OF WATER SUPPLY SOURCES
WILMINGTON METROPOLITAN AREA
GENERAL PLAN
SUSQUEHANNA RIVER ALTERNATE
DATED 1 SEPTEMBER 1959

PREPARED BY
ALBRIGHT & FRIEL INC.
CONSULTING ENGINEERS
PHILADELPHIA, PA.

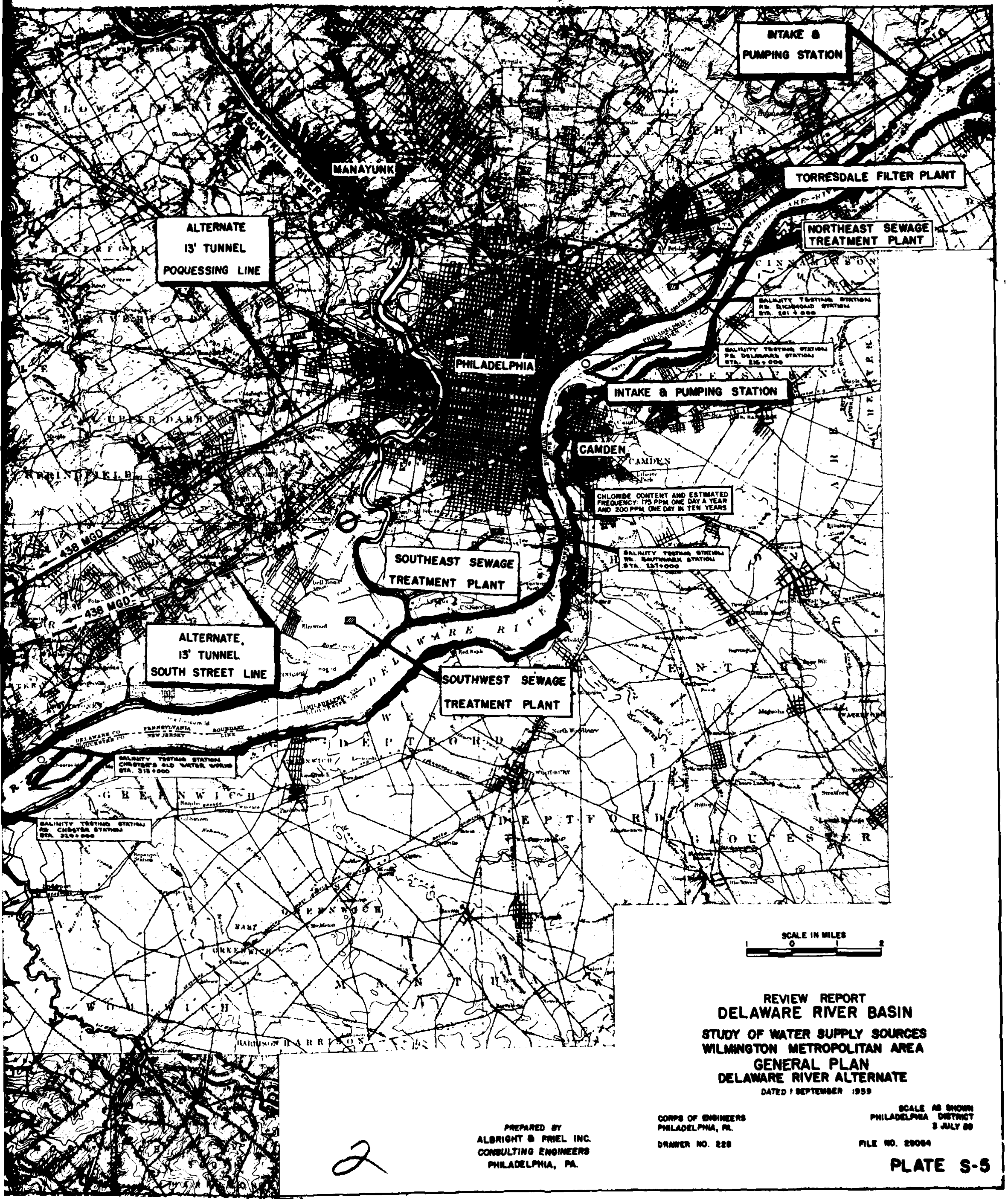
CORPS OF ENGINEERS
PHILADELPHIA, PA.
DRAWER NO. 226

SCALE AS SHOWN
PHILADELPHIA DISTRICT
3 JULY 59
FILE NO. 29033

PLATE S-4

3


LEGEND
VERTICAL SHAFT
TUNNEL OR PIPELINE
ALTERNATE LINE
NEW YORK
NEW JERSEY
PENNSYLVANIA
ATLANTIC OCEAN
MARYLAND
DELAWARE
VICINITY MAP
Magnetic North
WEST CHESTER
MEDIA
CHESTER
MARCUS HOOK
13' TUNNEL
438 MGD
EXISTING HOOPES RESEVOIR
54" PIPE FROM NEWARK RESERVOIR
66" PIPE
87 MGD
42" PIPE FROM CHRISTIANA RESERVOIR
WILMINGTON
PENNS GROVE
PENNSYLVANIA
DELAWARE
DELAWARE RIVER



REVIEW REPORT
DELAWARE RIVER BASIN
STUDY OF WATER SUPPLY SOURCES
WILMINGTON METROPOLITAN AREA
GENERAL PLAN
DELAWARE RIVER ALTERNATE
DATED 1 SEPTEMBER 1959

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PHILADELPHIA, PA.

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SCALE AS SHOWN
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3 JULY 59
FILE NO. 29064

PLATE S-5

2

EFFECTS OF SALT-WATER BARRIERS ACROSS THE DELAWARE RIVER

Preliminary Hydraulic Model Investigation

MISCELLANEOUS PAPER NO. 2-358

September 1959

U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

ARMY-MRC VICKSBURG, MISS.

APPENDIX S
ATTACHMENT 1

Preface

The tests reported herein were requested by the U. S. Army Engineer District, Philadelphia, in letter dated 4 March 1959, subject: "Estimate of Costs of Tests of a 'Barrier' Type Dam in the Delaware River Model." The study was performed in the Hydraulics Division, U. S. Army Engineer Waterways Experiment Station, during April and May 1959. Engineers directly concerned with the study were Messrs. E. P. Fortson, Jr., Chief, Hydraulics Division; G. B. Fenwick, Chief, Rivers and Harbors Branch; H. B. Simmons, Chief, Estuaries Section; and W. H. Bobb, project engineer. This report was prepared by Messrs. Simmons and Bobb.

Director of the Waterways Experiment Station during the performance of the tests and preparation of this report was Col. Edmund H. Lang, CE. Technical Director was Mr. J. B. Tiffany.

Contents

Summary

Because of the acute water-supply problem in the State of Delaware, it was suggested that a study be made of the possibility of using a barrier dam across the Delaware River to reduce the upstream limit of salt-water intrusion and thus provide more fresh water for industrial and domestic consumption. The dam was to incorporate either an ungated navigation opening (plan A) or locks to permit the passage of ships (plan B). During the study, it was found necessary to modify plan B to include a sump in the pool above the barrier with a gravity drain extending from the bottom of the sump to the lower pool, to collect the salt water passing through the locks during lockages and remove it from the upper pool.

Model tests were made principally in the existing model of the Delaware River, which is built to scales of 1:1000 horizontally and 1:1[illegible] vertically; however, tests of salt-water transfer through the locks [illegible] made to larger scales in a flume. The tests were performed under mea[illegible] conditions of tide and fresh-water discharge.

The tests, though preliminary in nature, permitted formulation of the following conclusions:

- a. Plan A would have no beneficial effects on salinities just upstream of the barrier because the upstream limit of salinity intrusion would not be reduced, the distance over which a given salinity concentration would move with the phase of tide would be reduced, and the average salinity over a tidal cycle at any location would thus be increased.
- b. Plan B would cause more extensive salinity intrusion than now occurs unless means are provided for removing from the upper pool the salt water which enters it from the locks during ship transits.
- c. Plan B modified by addition of a system of sumps and drains would probably effectively control intrusion of sea water into the upper pool, but pollution of this pool by municipal and industrial wastes would be greater than now occurs in that portion of the river because of elimination of tidal circulation.

d. Any barrier in the estuary which would afford an appreciable obstruction to the tidal wave would cause drastic changes in the tidal regimen. In reaches where the low-water plane would be lowered, compensatory dredging would be required to maintain navigable depths at mean low water.

EFFECTS OF SALT-WATER BARRIERS ACROSS THE DELAWARE RIVER

Preliminary Hydraulic Model Investigation

Introduction

1. The present primary source of fresh water for municipal and industrial use in the State of Delaware is wells. According to state officials, an ever-increasing population and stepped-up industrial activity will create an acute water-supply problem in the not-too-distant future unless present sources are supplemented. The Delaware River might provide all the fresh water needed if some means could be devised to hold the upstream limit of salt-water intrusion at about New Castle, Delaware. It was suggested by certain interests that a barrier dam, equipped with either a navigation opening or with locks to permit the passage of shipping, would accomplish the desired control over salinity intrusion. A preliminary model study was made to determine the feasibility of these two barrier types, and the results of the model tests are reported herein. The primary objective of the study was to determine the effects of the proposed barriers on salinities; however, the effects on tides and currents were observed and these data are also included.

2. The tests were accomplished primarily in the existing Delaware River model. Descriptions of the model and appurtenances and details of the model adjustment and verification are presented in Waterways Experiment Station Technical Memorandum No. 2-337, Delaware River Model Study, Reports Nos. 1 and 2, dated May 1956 and June 1954, and are not repeated in this report. These reports also discuss the model-to-prototype scale relations for time, velocity, discharge, etc. The scale relation for salinity, which is of particular interest to this study, is 1:1.

Base Tests

3. Tests of existing prototype conditions, or base tests, are made in connection with hydraulic model studies to provide a direct basis for evaluating the results of subsequent tests incorporating proposed plans.

A measurement of some phenomenon during a plan test, when compared to a similar measurement made during the base test, will provide a direct measure of the effects of the plan on the phenomenon in question. Base tests for this study were made for mean conditions of tide and fresh-water discharge. The simulated range of tide at the mouth of Delaware Bay was 4.1 ft, and simulated mean tide level was 3.1 ft. The above and all other elevations presented herein are referred to the Delaware River datum, which is 2.9 ft below mean sea level, Sandy Hook, 1929 adjustment. The total fresh-water discharge introduced upstream from the barrier site was 17,575 cfs, while an additional 2625 cfs was introduced into the major tributaries downstream from the barrier site, so that the total fresh-water flow was 20,200 cfs at the Capes. Base-test data obtained included tidal heights and salinities throughout the estuary, and current velocities at selected locations. Base-test data are not shown separately, but are included in tabulations and on plots for direct comparison with measurements made at similar locations with the plans installed.

Tests of Plan A

Description

4. Plan A consisted of a barrier dam across the Delaware River at channel station 201+150 with a navigation opening 500 ft wide at elevation -40 ft to permit the passage of shipping, and a 4000-ft-long spillway with a crest elevation of +6.0 ft mlw for the passage of peak fresh-water flows. Strings of dolphins to guide ships through the navigation opening from both the upstream and downstream directions were provided, and in effect formed funnels about 2000 ft long, 800 ft wide at the mouth, tapering to 500 ft wide at the barrier. The location of the barrier is shown in fig. 1, and a cross section of the structure is shown in fig. 2.

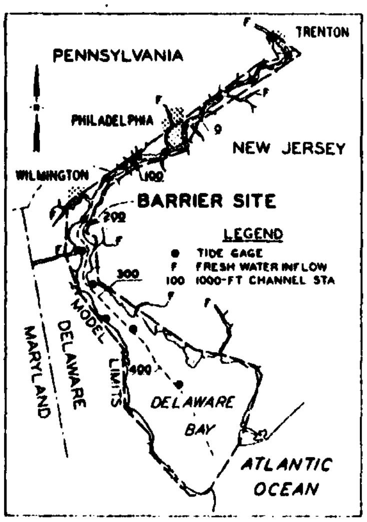


Fig. 1. Location map

Results of tests

5. Tests of plan A were made for the same conditions of tide and fresh-water discharge as was the base test described above. Tides, currents, and salinities were observed with the plan installed and are compared to base test observations in tables 1-4 and in figs. 3-6. Table 1 shows the results of tidal observations made at half-hourly intervals throughout a tidal cycle at the 16 gage locations shown in fig. 1, and at special gages located about 1000 ft from each side of the barrier dam and designated as "lower pool at barrier" and "upper pool at barrier." Table 2 presents a summary of tidal ranges and mean tide levels at all gages. Tidal elevations for base test and plan test conditions are plotted for three of the tide gages in fig. 3. Fig. 3a shows the tide curves for plan and base conditions for the special gage located just downstream from the barrier, and similar curves for the New Castle and Philadelphia gages are shown in figs. 3b and c, respectively. Fig. 4 is a plot of high- and low-water elevations throughout the estuary for base and plan A conditions. Velocity observations were made at eight locations between the bay and Philadelphia,

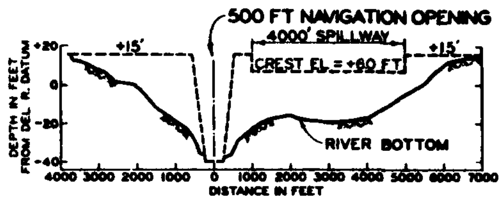
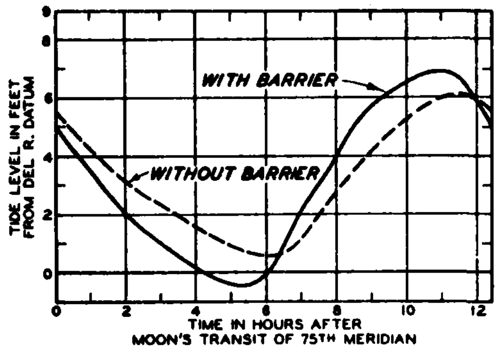
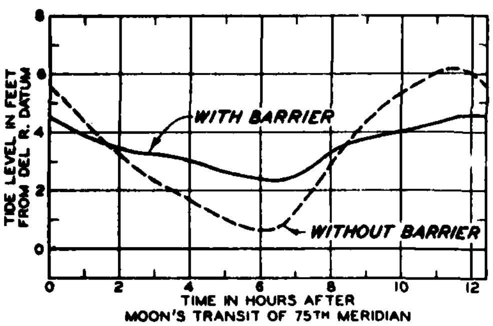


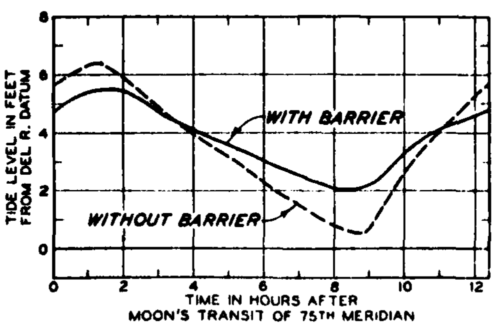
Fig. 2. Plan A barrier dam, looking downstream



a. Lower pool at barrier



b. New Castle gage



c. Philadelphia gage

Fig. 3. Effects of plan A on tides

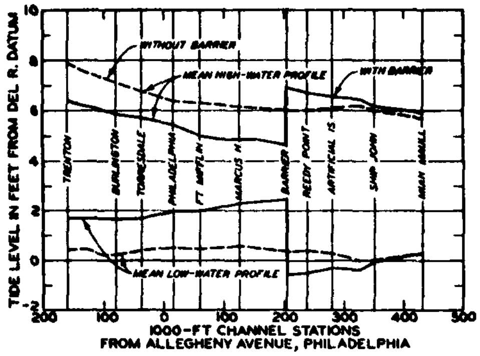


Fig. 4. Effects of plan A on water-surface elevations

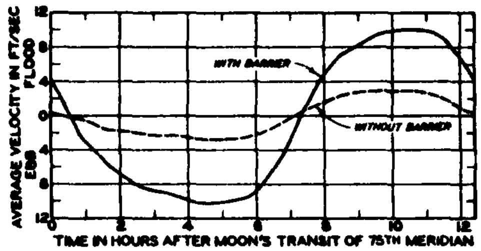


Fig. 5. Average velocities at location of navigation opening with and without plan A barrier

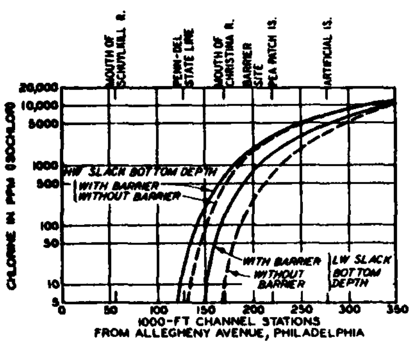


Fig. 6. Effect of plan A on salinity distribution, fresh-water discharge = 17,575 cfs

and are presented in table 3. The observations were made at half-hourly intervals at both surface and bottom. Velocity observations for the base test and plan A were also made at four depths on each of four verticals spaced uniformly across the navigation opening in the barrier. These observations were averaged with respect to time, and the average velocities thus derived are presented in fig. 5. The results of salinity observations made at surface and bottom along the center line of the navigation channel at the times of both high- and low-water slack are presented in table 4. The results of bottom salinity observations are also presented in graphic form in fig. 6.

Discussion of results

6. The results of the model tests indicate that plan A would cause large changes in the tidal regimen of the estuary. Immediately downstream from the barrier, the range of tide was increased by 1.8 ft and the time of high tide was advanced appreciably. Just upstream from the structure, the range of tide was reduced by more than one half, and significant reductions in range were noted at all tide gages to and including the Trenton gage.

7. Current velocities were reduced at essentially all stations observed except that located in the navigation opening of the barrier, with the greatest reductions occurring at stations located upstream from the

structure. In the navigation opening, maximum flood and ebb velocities were about 10.0 fps for plan A, as compared to about 3.0 fps in that location for the base test.

8. The barrier caused general increases in surface and bottom salinities at essentially all stations, the maximum increases occurring at low-water slack. In the region upstream from the barrier, bottom salinities at both high- and low-water slack were appreciably increased by the barrier. Also in this region, the distance between the locations of equal salinity concentrations at high- and low-water slack was reduced appreciably, with the result that the average salinity at a given point was significantly greater for the plan test than for the base test. On an over-all basis, the model tests indicated that salinity conditions would be appreciably worsened by the barrier throughout that reach of the river in which salinity control is desired.

9. It is believed that the detrimental rather than beneficial effects of plan A on salinity intrusion are attributable primarily to the reductions in tidal current velocities effected by the plan. Since the tidal currents constitute the major effective force in vertical mixing of salt and fresh water, and since reduced mixing is almost invariably accompanied by more extensive penetration of sea water into an estuary, it follows that any scheme which reduces the tidal current velocities will increase rather than decrease salinity intrusion. The fact that the plan effected a local reduction in cross-sectional area, with accompanying high current velocities in the navigation opening, was insignificant in relation to the over-all reduction in the mixing forces. Since the ungated navigation opening permitted access of salt water to the upstream region of the estuary, it follows that with the barrier installed salinities within this region would be as high as or higher than for existing conditions.

Tests of Plan B

Description

10. The location of the plan B barrier was the same as that of plan A. For plan B, four navigation locks were incorporated in the barrier at the location of the existing navigation channel, and a 4000-ft-long

spillway, with a crest elevation of +8.0 ft to prevent overtopping by the tides, was provided for the passage of floods. Two of the navigation locks were 1200 ft long by 170 ft wide by 40 ft deep, and the remaining two were 500 ft long by 80 ft wide by 40 ft deep. The location of plan B is shown in fig. 1, a cross section of the structure is shown in fig. 7, a cross section of the locks in fig. 8, and a plan view of the locks in fig. 9.

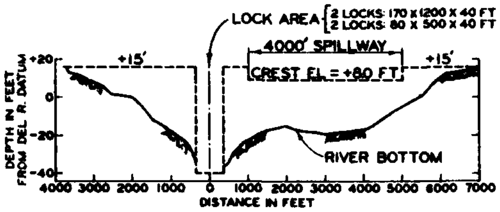


Fig. 7. Plan B barrier dam, looking downstream

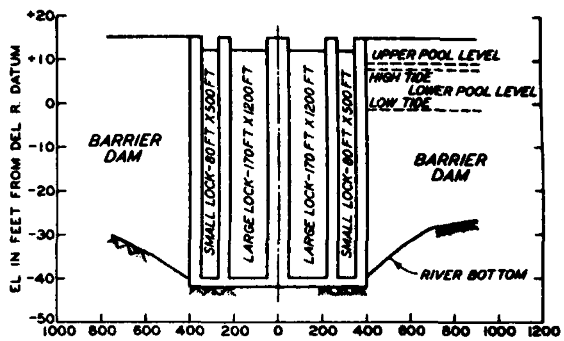


Fig. 8. Plan B barrier lock section

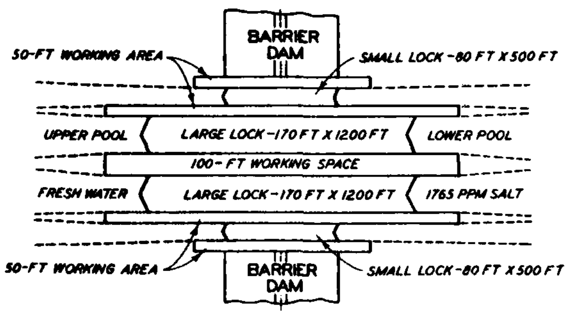


Fig. 9. Locks for plan B barrier

Test procedure

11. In the case of all conventional locks connecting bodies of salt and fresh water, there is a transfer of salt water from the salt-water body to the locks, and from the locks to the fresh-water body, when the gates are opened to allow ships to enter or leave the locks. This transfer of salt water is attributable to the greater density of the salt water as compared to the fresh water, and the amount of salt water thus transferred per unit of time is dependent primarily on the dimensions of the lock, the difference in salinity of the water on the upstream and downstream sides of the lock gates, and the number of ship transits.

12. The scales of the existing Delaware River model, especially the horizontal scale (1:1000) and the time scale (1:100), were too small for reliable determination of salt transfer rates through the locks. The procedures followed in testing plan B were, therefore, as follows: (a) the barrier was installed in the Delaware River model, and its effects on tides, tidal currents, and salinities downstream from the structure were

determined; (b) undistorted scale models of the large and small locks were constructed in an existing flume, and appropriate tests were made to determine the average amount of salt which would be transferred through each lock size per ship transit; (c) information derived from the lock tests was applied to the estimated traffic schedule through the locks, and the resulting rate of salt transfer per unit of time was determined and was introduced into the fresh-water pool of the Delaware River model at the lock site; and (d) observations were carried out to determine the effects of the intruding salt water on salinity conditions in the fresh-water pool.

Tests to determine salt transfer rates

13. An existing 1.5-ft-deep by 0.75-ft-wide lucite flume, which was equipped with the necessary appurtenances for control of salt-water concentrations, was used for the supplemental tests to determine the rate of salt transfer through the locks. One large and one small lock were simulated in turn in this flume, utilizing the width of the flume as the scale width of the lock, which resulted in an undistorted linear scale of 1:227 for the large lock and 1:107 for the small lock. The resulting time scales were 1:15.1 for the large lock and 1:10.4 for the small lock.

14. The pool downstream from the locks was maintained at mean-tide level with the plan installed, as determined from observations made in the Delaware River model, and at the average salinity at the barrier site for existing conditions (1765 ppm total salt). The level of the upper pool was also maintained at that observed in the Delaware River model with the barrier installed and with average fresh-water discharge. The upper pool contained only fresh water at the beginning of each test.

15. Examination of operating data for a number of locks of sizes comparable to those under consideration indicated that the average time for the gates to be open for ships entering and leaving the locks would be about 15 minutes for the large lock and about 10 minutes for the small lock. Consequently, the following procedures were followed to determine the average salt transfer per ship transit for each lock: (a) starting with salt water in the lower pool and fresh water in the lock and upper pool, the lower lock gate was opened for the appropriate time and then closed, the lock was filled to upper pool level which required an estimated 10 min for either size lock, the upper gate was opened for the appropriate

time and then closed, thus simulating a ship transit from the lower pool to the upper pool; (b) the sequence just described was reversed to simulate a ship transit from the upper pool to the lower pool; (c) these procedures were repeated alternately until salinity measurements made in the lock indicated that the salinity was stable; and (d) the water in the lock was mixed thoroughly, the average salinity was determined, and the number of pounds of salt contained in the lock was computed. This procedure yielded an accurate measure of the amount of salt contained in the lock after stability had been attained and after the upper gate had been opened in normal operation. The procedure was then repeated exactly except that, after stability of salinity in the lock was attained, the water in the lock was mixed thoroughly and the average salinity was determined before the upper gate was opened. The difference between the number of pounds of salt contained in the lock before and after opening of the upper gate was thus indicative of the amount which passed through the upper gate into the fresh-water pool for stable conditions.

16. The results of the above-described tests indicated that the average transfer of salt per ship transit was 41.0 tons for the large lock and 18.1 tons for the small lock. It was estimated by the Philadelphia District that each of the two large locks would be used six times per day, for a total of 12 lockages, and each of the small locks would be used 40 times per day, for a total of 80 lockages. For this estimated traffic schedule, the test results indicate that the daily salt transfer rate for all locks would be ~~492~~ 1940 tons. The test results also indicated that the average salinity of the salt water which would enter the upper pool from the locks would be 1000 ppm. In simulating salt transfer in the Delaware River model, a constant inflow of 695 cfs at a concentration of 1000 ppm, equal to a daily salt transfer rate of ~~492~~ 1940 tons, was introduced into the upper pool at the location of the upper lock gates.

Results of tests

17. The effects of plan B on tidal phenomena downstream from the structure are shown in tables 1 and 2 and figs. 10 and 11. Half-hourly measurements of tidal elevations at each of the 6 gages located downstream from the barrier are recorded in table 1, and the effects of the plan on tidal ranges and mean-tide levels are shown in table 2. The tide curves

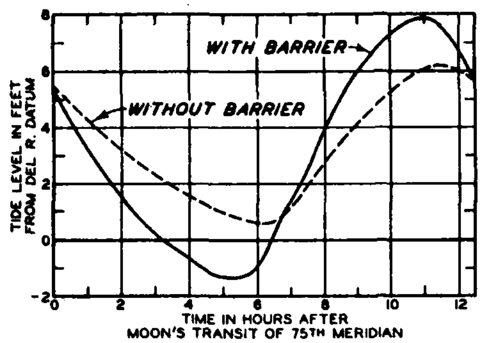


Fig. 10. Effects of plan B on tides, lower pool at barrier

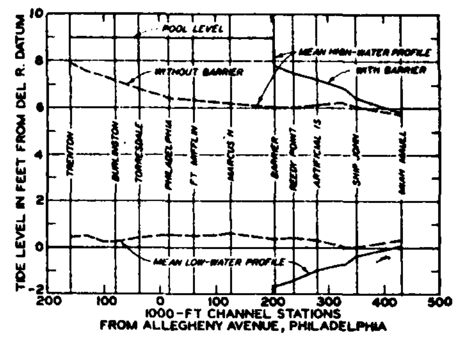


Fig. 11. Effects of plan B on water-surface elevations

for plan B conditions at the gage just downstream from the barrier are plotted in fig. 10, and the effects of the plan on high- and low-water planes and mean-tide level are shown in fig. 11.

18. The effects of the plan on tidal current velocities are shown in table 3, which presents half-hourly measurements of current velocity over a complete tidal cycle at 3 current velocity stations. Since tidal effects were eliminated in that reach of the river upstream from the barrier, current velocities were observed only at stations downstream from the structure.

19. The effects of plan B on salinity conditions in the upper pool are shown in fig. 12. Since there was essentially no mixing of the salt and fresh water in the upper pool, it was only necessary to observe the elevation of the salt-fresh water interface at various times following the beginning of the test. These observations were facilitated by adding a small amount of methylene blue chloride dye to the inflowing salt water, then observing periodically the elevation of the dyed salt-water interface.

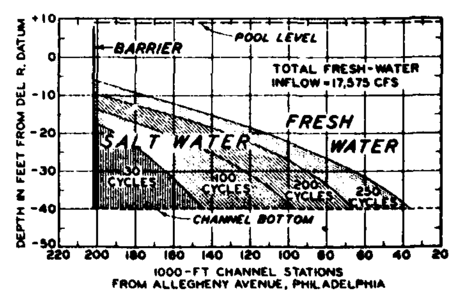


Fig. 12. Salt-water movement into upper pool, plan B without scavenger sump

Discussion of results

20. Plan B caused drastic changes in the tidal regimen of the estuary downstream from the structure. The range of tide at the gage just

downstream from the barrier was increased by about 3.8 ft, and the times of high tide and low tide were advanced by about one hour. Tidal current velocities were reduced at all stations, thus indicating that the tidal prism was reduced appreciably.

21. The salinity test was continued for a period of time equal to 250 tidal cycles (about four months, prototype), at which time the tip of the well-developed salt-water wedge reached channel station 36+000, or about the vicinity of the Walt Whitman Bridge. The elevation of the salt-fresh water interface at the barrier at this time was about -5.0 ft, indicating that little if any salt water had been lost from the upper pool over the spillway.

22. The test was discontinued at tidal cycle 250, since it was obvious that essentially the entire upper pool would become contaminated in time. The fresh-water discharge reproduced for the test was the average discharge which, for existing conditions, holds the 100 isochlor well downstream from the Pennsylvania-Delaware State line. It was therefore concluded that some means for evacuating salt water from the upper pool would have to be devised; otherwise, salinity intrusion for plan B conditions would be much worse than for existing conditions.

Tests of Modified Plan B

Description

23. Plan B was modified to include a salt-water scavenger sump in the upper pool, with a gravity drain connecting the bottom of the sump to the lower pool downstream from the barrier. The purpose of the scavenger sump and drain was to collect the salt water passing through the locks as a result of ship traffic and remove it from the upper pool. The sump was 2000 ft long, 800 ft wide, with a bottom elevation of -50 ft, and was located on the channel center line about 5000 ft upstream from the barrier. The gravity drain was designed to pass an average discharge of 2000 cfs (over a tidal cycle), which is about equal to the minimum daily fresh-water discharge.

Results of tests

24. The effects of modified plan B on tides and tidal currents were

identical with those of the original plan B, and are not included in this report. The salinity test was conducted in the same manner as the original plan B, using data from the flume tests as a basis for simulating the rate of salt transfer through the locks. The salinity test was continued until salinity conditions in the upper pool had stabilized, and the salinity conditions of the upper pool at this time are presented in fig. 13. For this test, 2000 cfs of the total fresh-water discharge of 17,575 cfs passed through the scavenger drain, and the remaining 15,575 cfs passed over the barrier spillway.

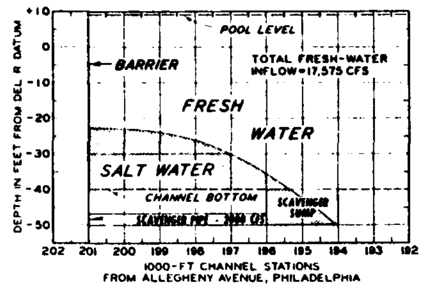


Fig. 13. Salt-water movement into upper pool, plan B with scavenger sump

Discussion of results

25. The modified plan B would effect the same drastic changes in tides and tidal currents as the original plan B; however, the salinity test indicated that the modified plan would effectively control salinity intrusion into the upper pool. At the time of salinity stability in the upper pool, no salt water had intruded beyond the upstream end of the scavenger sump at channel station 194+000, and the elevation of the salt-fresh water interface at the barrier was about -23 ft.

26. After salinity conditions in the upper pool had stabilized, and the observations presented in fig. 13 had been obtained, the total fresh-water discharge into the upper pool was reduced from 17,575 cfs to 2000 cfs to determine whether that portion of the fresh-water discharge passing over the spillway had any effect on salinity conditions in the upper pool. Subsequent observations showed no measurable change in salinity conditions in the upper pool, thus indicating that only that portion of the fresh-water discharge which passed through the scavenger drain was effective in controlling salinity intrusion.

Conclusions

27. The tests reported herein were of a preliminary nature and were designed to determine whether the principles of certain proposed improvement plans were sound, rather than to establish the quantitative degree of

improvement which would be effected by the plans. On the basis of these tests, the following general conclusions have been reached:

- a. A barrier in the Delaware Estuary, having an ungated opening similar to that of plan A, would have no beneficial effects on salinities in the region just upstream from the barrier site. The distance over which a given salinity concentration would move with the phase of tide would be reduced, and the average salinity over a tidal cycle at any location would thus be increased.
- b. A barrier equipped with navigation locks, rather than an ungated opening for navigation, would cause more extensive salinity intrusion than now exists unless some means is provided for removing from the upper pool the salt water which enters through the locks during ship transits.
- c. The addition of an appropriate system of scavenger sumps and drains to a navigation-lock type of barrier would probably constitute an effective means for controlling the intrusion of sea water into the upper pool. However, it appears that pollution of the pool upstream from the barrier by municipal and industrial wastes would be much worse than pollution of that portion of the river under existing conditions, because of the elimination of tidal circulation, so that other means for disposal of such wastes would probably be necessary.
- d. Any barrier in the estuary which would afford an appreciable obstruction to the tidal wave would cause drastic changes in the tidal regimen. The maximum change would be caused by a navigation-lock type of barrier, as illustrated by the effects of plan B. In reaches where the low-water plane would be lowered, compensatory dredging would be required to maintain the necessary navigable depth at mean low water.

APPENDIX S - ATTACHMENT 1

Table 1

Effect of Barriers on Tidal Elevations

Mean Tide, Mean Fresh-Water Flow

	Elevations at														
	Miah Maull Shoal Sta 431+000			Ship John Shoal Sta 350+000			Woodland Beach Sta 325+000			Artificial Island Sta 278+000			Reedy Point Sta 233+000		
Time	Base Test	Plan A	Plan B	Base Test	Plan A	Plan B	Base Test	Plan A	Plan B	Base Test	Plan A	Plan B	Base Test	Plan A	Plan B
0	2.6	2.7	2.6	3.3	3.7	4.0	3.8	4.0	4.4	4.4	4.5	4.9	4.9	4.8	5.1
0.5	2.1	2.0	2.1	2.8	3.0	3.1	3.1	3.3	3.5	3.7	3.6	3.9	4.2	3.8	4.2
1	1.5	1.4	1.4	2.3	2.2	2.4	2.6	2.5	2.7	3.1	2.9	2.9	3.5	3.1	3.2
1.5	1.0	0.9	0.9	1.8	1.6	1.7	2.1	1.8	1.9	2.5	2.2	2.2	3.0	2.5	2.3
2	0.7	0.5	0.4	1.2	1.0	1.1	1.6	1.2	1.3	2.1	1.6	1.4	2.4	2.0	1.4
2.5	0.5	0.4	0.1	0.8	0.5	0.5	1.1	0.7	0.7	1.6	1.0	0.8	2.0	1.3	0.8
3	0.4	0.4	0.2	0.4	0.2	0.0	0.6	0.3	0.1	1.2	0.6	0.2	1.5	0.8	0.2
3.5	0.6	0.6	0.4	0.2	0.1	-0.4	0.3	-0.1	-0.4	0.8	0.2	-0.3	1.2	0.3	-0.4
4	1.0	0.9	0.6	0.2	0.1	-0.4	0.1	-0.3	-0.7	0.5	-0.2	-0.8	0.8	0.1	-0.8
4.5	1.4	1.4	1.0	0.5	0.2	-0.2	0.2	-0.2	-0.6	0.3	-0.3	-1.0	0.5	-0.2	-1.1
5	1.8	1.9	1.7	1.0	0.7	0.2	0.6	0.3	-0.1	0.3	-0.1	-0.9	0.4	-0.4	-1.4
5.5	2.5	2.6	2.5	1.5	1.3	0.8	1.1	1.1	0.5	0.7	0.5	-0.3	0.4	-0.3	-1.3
6	3.1	3.2	3.1	2.2	2.0	1.6	1.8	1.7	1.2	1.3	1.2	0.2	0.6	0.3	-0.6
6.5	3.8	3.9	3.6	3.0	2.8	2.5	2.5	2.5	2.1	2.0	1.8	0.9	1.3	1.2	0.2
7	4.4	4.4	4.2	3.8	3.6	3.2	3.4	3.3	3.0	2.7	2.7	2.0	1.9	2.1	1.4
7.5	4.9	4.9	4.6	4.6	4.3	3.9	4.1	4.3	3.8	3.4	3.6	3.0	2.6	3.2	2.6
8	5.4	5.2	5.1	5.2	4.9	3.7	4.9	4.9	4.6	4.1	4.5	3.9	3.4	4.1	3.9
8.5	5.7	5.6	5.5	5.7	5.4	5.3	5.4	5.4	5.4	4.7	5.1	4.8	4.1	4.9	5.0
9	5.8	5.8	5.8	6.0	5.9	5.8	5.9	5.9	5.9	5.2	5.6	5.7	4.7	5.6	5.9
9.5	5.7	5.8	5.8	6.2	6.2	6.4	6.2	6.2	6.5	5.6	6.1	6.5	5.3	6.0	6.6
10	5.5	5.5	5.6	6.1	6.2	6.5	6.3	6.5	6.9	6.0	6.6	7.0	5.6	6.4	7.2
10.5	5.0	5.1	5.2	5.8	6.0	6.3	6.1	6.3	6.8	6.1	6.6	7.2	6.0	6.6	7.5
11	4.5	4.6	4.7	5.4	5.5	5.9	5.7	5.8	6.4	5.9	6.3	7.0	6.1	6.7	7.6
11.5	3.8	4.0	4.0	4.6	4.9	5.3	5.1	5.3	5.8	5.5	5.8	6.4	6.0	6.3	7.2
12	3.2	3.4	3.3	4.0	4.3	4.6	4.4	4.6	5.0	5.0	5.2	5.7	5.6	5.7	6.3

(Continued)

Note: Elevations are in feet and refer to Delaware River datum, which is 2.9 ft below mean sea level, Sandy Hook, 1929 adjustment. Channel stations are from Allegheny Ave., Philadelphia. Time is in hours after the moon's transit of the 75th meridian.

APPENDIX S - ATTACHMENT 1

Table 1 (Continued)

	Elevations at													
	Lower Pool at Barrier Sta 202+000			Upper Pool at Barrier Sta 201+000		New Castle Sta 198+000		Edgemoor Sta 157+000		Marcus Hook Sta 124+000		Baldwin Sta 96+000	
Time	Base Test	Plan A	Plan B	Base Test	Plan A	Base Test	Plan A	Base Test	Plan A	Base Test	Plan A	Base Test	Plan A
0	5.5	5.2	5.5	5.5	4.5	5.5	4.5	6.1	4.9	6.2	4.9	6.0	4.9
0.5	5.0	4.3	4.4	4.9	4.3	5.0	4.2	5.6	4.7	5.9	4.9	6.0	4.9
1	4.3	3.6	3.3	4.2	3.8	4.3	3.9	5.0	4.4	5.4	4.7	5.7	4.8
1.5	3.7	2.8	2.5	3.7	3.6	3.7	3.6	4.3	4.0	4.9	4.3	5.2	4.7
2	3.2	2.1	1.7	3.2	3.5	3.2	3.4	3.8	3.7	4.2	4.0	4.6	4.3
2.5	2.7	1.5	0.9	2.7	3.3	2.7	3.3	3.2	3.5	3.7	3.8	4.1	4.0
3	2.3	1.0	0.4	2.3	3.2	2.3	3.2	2.8	3.4	3.2	3.7	3.7	3.9
3.5	2.0	0.5	-0.2	2.0	3.1	2.0	3.1	2.4	3.3	2.8	3.5	3.3	3.7
4	1.6	0.2	-0.6	1.6	3.0	1.6	3.0	2.1	3.2	2.4	3.3	3.0	3.5
4.5	1.3	-0.1	-1.1	1.2	2.8	1.3	2.8	1.7	3.0	2.1	3.2	2.6	3.3
5	1.0	-0.4	-1.5	1.0	2.6	1.0	2.6	1.4	2.8	1.7	3.0	2.2	3.1
5.5	0.8	-0.4	-1.6	0.7	2.5	0.7	2.5	1.1	2.6	1.3	2.8	1.9	2.9
6	0.6	-0.2	-1.1	0.6	2.3	0.6	2.3	0.9	2.4	1.1	2.6	1.5	2.6
6.5	0.7	1.0	0.3	0.7	2.3	0.7	2.3	0.7	2.3	0.8	2.3	1.1	2.4
7	1.2	2.0	1.4	1.2	2.5	1.3	2.5	0.7	2.3	0.6	2.2	0.9	2.2
7.5	2.0	3.0	2.6	2.0	2.8	2.0	2.8	1.2	2.4	0.7	2.2	0.6	2.1
8	2.8	4.0	4.0	2.8	3.3	2.9	3.3	2.1	2.8	1.4	2.5	0.9	2.2
8.5	3.6	5.0	5.0	3.7	3.6	3.6	3.6	2.9	3.3	2.3	2.9	1.5	2.5
9	4.2	5.7	5.9	4.3	3.7	4.3	3.7	3.8	3.6	3.0	3.4	2.4	3.0
9.5	4.8	6.2	6.7	4.9	3.9	4.9	3.9	4.4	3.9	3.8	3.7	3.1	3.4
10	5.3	6.5	7.2	5.3	4.0	5.3	4.0	4.9	4.2	4.5	4.0	3.8	3.7
10.5	5.7	6.8	7.7	5.7	4.2	5.6	4.1	5.4	4.3	5.0	4.3	4.5	4.0
11	6.0	6.9	7.8	6.0	4.4	6.0	4.3	5.8	4.6	5.5	4.4	5.0	4.3
11.5	6.1	6.7	7.5	6.1	4.5	6.1	4.5	6.2	4.8	5.9	4.7	5.5	4.5
12	6.0	6.0	6.6	5.9	4.6	6.0	4.6	6.2	4.9	6.1	4.9	5.8	4.7

(Continued)

APPENDIX S - ATTACHMENT 1

Table 1 (Concluded)

	Elevations at													
	Ft. Mifflin Sta 60+000		Philadelphia Sta 15+000		Torresdale Sta -38+000		Burlington Sta -81+000		Florence Sta -104+000		Fieldsboro Sta -129+000		Trenton Sta -160+000	
Time	Base Test	Plan A	Base Test	Plan A	Base Test	Plan A	Base Test	Plan A	Base Test	Plan A	Base Test	Plan A	Base Test	Plan A
0	6.1	4.9	5.7	4.8	4.8	4.4	4.5	4.3	4.5	4.5	4.4	4.7	4.6	4.8
0.5	6.3	5.0	6.1	5.1	5.5	4.9	5.3	4.9	5.3	5.1	5.3	5.2	5.5	5.3
1	6.2	5.0	6.4	5.4	6.1	5.3	6.1	5.3	6.0	5.5	6.1	5.6	6.2	5.7
1.5	5.8	5.0	6.4	5.5	6.5	5.6	6.6	5.6	6.7	5.8	6.7	5.9	6.8	5.9
2	5.3	4.8	6.2	5.4	6.7	5.7	7.0	5.9	7.1	6.0	7.2	6.1	7.3	6.2
2.5	4.7	4.4	5.7	5.1	6.5	5.6	7.1	5.9	7.4	6.1	7.6	6.3	7.7	6.3
3	4.3	4.2	5.0	4.7	6.0	5.3	6.8	5.8	7.2	6.0	7.6	6.3	7.8	6.4
3.5	3.9	3.9	4.6	4.4	5.5	4.9	6.4	5.4	6.8	5.7	7.5	6.0	7.4	6.2
4	3.5	3.7	4.1	4.1	4.9	4.5	5.8	5.0	6.1	5.3	6.6	5.6	6.6	5.7
4.5	3.1	3.5	3.7	3.8	4.5	4.1	5.3	4.6	5.5	4.8	5.8	5.1	5.8	5.1
5	2.8	3.2	3.3	3.6	4.0	3.8	4.6	4.1	4.9	4.3	5.1	4.5	5.2	4.6
5.5	2.4	3.0	2.9	3.3	3.5	3.4	4.0	3.7	4.3	3.8	4.4	4.0	4.6	4.2
6	2.0	2.9	2.4	3.1	3.0	3.1	3.5	3.3	3.6	3.5	3.9	3.6	3.9	3.7
6.5	1.6	2.6	2.0	2.8	2.5	2.8	3.0	3.0	3.2	3.1	3.3	3.3	3.5	3.5
7	1.2	2.3	1.6	2.5	2.0	2.6	2.5	2.7	2.7	2.8	2.9	3.0	3.0	3.1
7.5	0.9	2.1	1.2	2.3	1.5	2.4	2.1	2.4	2.3	2.6	2.5	2.7	2.7	2.9
8	0.7	2.0	0.9	2.1	1.1	2.1	1.6	2.2	1.8	2.3	2.0	2.4	2.2	2.7
8.5	0.9	2.1	0.7	2.0	0.8	1.9	1.3	2.0	1.4	2.1	1.7	2.2	1.7	2.5
9	1.8	2.5	0.9	2.2	0.6	1.7	0.9	1.8	1.0	1.9	1.2	2.0	1.3	2.2
9.5	2.7	3.1	1.8	2.6	0.5	1.8	0.6	1.8	0.7	1.7	0.9	1.8	1.0	2.0
10	3.6	3.6	2.8	3.2	1.3	2.2	0.5	1.7	0.4	1.7	0.6	1.7	0.7	1.8
10.5	4.2	3.9	3.5	3.7	2.3	2.9	1.3	2.1	0.7	1.9	0.4	1.7	0.5	1.7
11	4.8	4.2	4.2	4.0	3.0	3.3	2.2	2.7	1.7	2.5	0.9	2.1	0.6	2.0
11.5	5.3	4.4	4.7	4.3	3.6	3.7	2.8	3.2	2.5	3.2	2.2	3.1	2.6	3.1
12	5.8	4.6	5.3	4.5	4.2	4.0	3.5	3.8	3.4	3.9	3.6	4.0	3.7	4.2

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Table 2

Effects of Barriers on Tidal Ranges and Levels

Mean Tide, Mean Fresh-Water Flow

1000-ft Channel Station	Gage	Base Test Range ft	Base Test Mean Tide Level	Plan A Range ft	Plan A Mean Tide Level	Plan B Range, ft	Plan B Mean Tide Level
	Breakwater	4.1	3.1	4.1	3.1	4.1	3.1
431	Miah Maull Shoal	5.4	3.1	5.6	3.1	5.7	3.0
350	Ship John Shoal	5.8	3.1	6.2	3.1	6.9	3.1
325	Woodland Beach	6.0	3.2	6.9	3.0	7.5	3.1
278	Artificial Island	5.8	3.2	6.9	3.1	8.2	3.1
233	Reedy Point	5.6	3.2	7.2	3.1	9.0	3.1
202	Lower pool at barrier	5.6	3.3	7.4	3.2	9.4	3.1
201	Upper pool at barrier	5.6	3.3	2.2	3.5	Upper pool elevation = +9.0 ft with mean fresh-water flow and spillway crest +8.0 ft	
198	New Castle	5.6	3.3	2.2	3.5		
157	Edgemoor	5.7	3.4	2.6	3.6		
124	Marcus Hook	5.8	3.4	2.8	3.5		
96	Baldwin	5.9	3.5	2.8	3.5		
60	Fort Mifflin	5.9	3.5	3.0	3.5		
15	Philadelphia	6.0	3.6	3.5	3.7		
-38	Trenton	6.2	3.6	4.0	3.7		
-81	Burlington	6.6	3.9	4.2	3.8		
-104	Florence	6.7	4.2	4.4	3.9		
-129	Fieldsboro	6.9	4.3	4.5	4.0		
-160	Trenton	7.0	4.5	4.7	4.1		

Note: Elevations of mean tide level are in feet and refer to Delaware River datum, which is 2.9 ft below mean sea level, Sandy Hook, 1929 adjustment. Channel stations are from Allegheny Ave., Philadelphia.

APPENDIX S - ATTACHMENT 1

Table 3

Effect of Barriers on Current Velocities

Mean Tide, Mean Fresh-Water Flow

	Velocities at Station 25 1700 ft Right of Channel Sta 371+000						Velocities at Station 34 1820 ft Right of Channel Sta 275+550					
	Base Test		Plan A		Plan B		Base Test		Plan A		Plan B	
Time	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
0	E 1.8	E 1.1	E 2.0	E 1.4	E 3.6	E 2.1	E 1.1	E 0.1	E 1.9	E 0.1	E 3.3	E 2.0
0.5	2.2	1.5	2.6	1.9	4.0	2.5	1.8	0.9	2.0	0.6	3.1	2.0
1	2.7	1.6	3.2	1.9	4.3	2.5	2.4	1.3	2.1	1.0	2.8	2.0
1.5	3.1	1.7	3.5	2.0	4.5	2.5	2.6	1.9	2.1	1.4	2.6	1.8
2	3.5	2.0	3.8	2.0	4.2	2.3	2.6	2.2	2.2	1.5	2.3	1.5
2.5	3.9	2.0	4.0	2.0	3.7	2.0	2.6	2.2	2.1	1.5	2.0	1.3
3	4.0	1.7	3.5	1.5	3.2	1.6	2.6	2.2	2.0	1.5	1.9	1.1
3.5	3.4	1.4	2.9	1.0	2.5	1.2	2.5	2.0	2.0	1.5	1.9	0.9
4	2.8	0.9	2.1	0.5	1.4	0.5	2.4	2.0	1.9	1.3	1.6	0.7
4.5	1.7	0.3	1.0	F 0.2	0.5	F 0.2	2.2	1.7	1.6	1.0	1.0	0.5
5	0.8	F 0.1	0.0	0.8	F 0.5	1.0	2.0	1.4	1.4	0.6	0.2	0.0
5.5	0.0	0.6	F 0.6	1.1	1.3	1.8	1.7	1.0	0.9	0.2	F 0.2	F 0.6
6	F 0.6	1.1	1.4	1.5	2.7	2.5	1.0	0.4	0.1	F 0.3	0.9	1.5
6.5	1.4	1.5	1.9	1.9	2.7	2.9	0.0	F 0.2	F 0.5	1.0	1.9	1.8
7	1.9	1.9	1.9	2.2	2.5	3.2	F 0.7	0.9	1.0	1.5	3.2	2.0
7.5	1.9	2.2	1.9	2.4	2.4	3.2	1.5	1.6	1.6	1.5	3.2	2.2
8	1.7	2.3	1.5	2.3	2.1	2.9	2.1	1.8	2.1	1.5	2.4	2.0
8.5	1.5	2.1	1.3	2.0	2.0	2.5	2.4	1.9	2.0	1.5	1.9	1.7
9	1.3	1.8	1.1	1.6	1.8	2.1	2.5	1.9	1.6	1.3	1.1	1.2
9.5	1.0	1.5	1.0	1.5	1.2	1.5	2.5	1.8	1.3	1.1	0.6	0.9
10	0.7	1.0	0.5	1.3	0.5	0.7	2.6	1.7	1.0	1.0	0.1	0.6
10.5	0.2	0.5	0.0	0.9	0.0	0.0	1.6	1.3	0.6	0.9	E 0.1	0.3
11	E 0.4	0.1	E 0.9	0.1	E 1.0	E 0.5	0.9	1.0	0.2	0.5	0.7	0.0
11.5	0.9	E 0.2	1.4	E 0.6	1.1	1.1	0.4	0.5	E 0.5	0.1	1.8	E 0.5
12	1.5	0.7	2.0	1.4	3.0	1.9	E 0.3	0.2	1.4	0.0	2.7	1.1

(Continued)

Note: Velocities are in feet per second prototype. Channel stations are from Allegheny Ave., Philadelphia. Time is in hours after the moon's transit of the 75th meridian. "E" denotes ebbing currents. "F" denotes flooding currents.

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Table 3 (Continued)

Time	Velocities at Station 57 700 ft Left of Channel Sta 19+050				Velocities at Station 125-B 580 ft Right of Channel Sta 125+000				Velocities at Station 160-A 1120 ft Left of Channel Sta 160+000			
	Base Test		Plan A		Base Test		Plan A		Base Test		Plan A	
	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
0	F 3.0	F 2.5	F 1.7	F 1.4	F 0.8	F 0.7	E 0.1	F 0.3	F 1.6	F 1.3	F 1.4	F 0.7
0.5	2.8	2.2	1.5	1.2	0.4	0.1	0.2	0.1	0.6	0.7	1.0	0.4
1	2.0	1.7	1.2	0.7	0.0	E 0.3	0.3	E 0.2	E 0.2	E 0.2	0.3	0.1
1.5	1.2	1.0	0.7	0.3	E 0.4	0.6	0.4	0.5	1.2	0.8	E 0.3	E 0.2
2	0.2	0.0	0.0	0.0	1.2	1.0	0.7	0.7	2.0	1.3	1.1	0.5
2.5	E 0.8	E 0.7	E 0.5	E 0.5	1.8	1.5	1.3	0.9	2.5	1.6	1.5	0.7
3	1.8	1.4	1.3	1.2	1.9	1.9	1.4	1.2	2.9	1.8	1.9	0.9
3.5	2.5	1.9	1.9	1.4	1.9	1.8	1.4	1.3	3.3	2.0	2.0	1.0
4	3.1	1.8	2.0	1.4	2.1	1.7	1.4	1.4	3.6	2.0	2.2	1.0
4.5	3.1	1.6	2.0	1.4	2.2	1.6	1.4	1.1	3.6	2.0	2.4	1.0
5	2.9	1.6	1.9	1.2	2.3	1.4	1.4	1.0	3.7	2.1	2.3	1.0
5.5	2.7	1.6	1.7	1.1	2.3	1.4	1.4	1.0	3.7	2.2	2.3	1.2
6	2.4	1.5	1.5	1.1	2.3	1.4	1.4	1.1	3.5	2.1	2.1	1.4
6.5	2.2	1.5	1.4	1.1	2.2	1.3	1.3	0.8	3.2	1.8	2.0	1.2
7	2.1	1.3	1.2	1.0	1.8	0.8	1.2	0.6	2.3	1.5	1.6	1.0
7.5	1.9	1.2	1.0	0.8	1.1	0.4	0.6	0.3	1.1	0.9	1.0	0.7
8	1.9	1.0	1.0	0.6	0.1	F 0.2	0.2	0.0	F 0.1	0.0	0.5	0.2
8.5	1.4	0.7	0.9	0.4	F 0.9	1.0	F 0.3	F 0.3	1.4	F 1.1	F 0.2	F 0.2
9	0.5	0.1	0.4	0.1	1.8	1.6	0.8	0.8	2.3	2.0	0.9	0.9
9.5	F 0.6	F 0.8	F 0.3	F 0.3	1.5	1.7	1.1	1.3	3.1	2.8	1.3	1.4
10	1.9	1.8	0.9	1.0	1.3	1.7	1.0	1.2	3.3	2.9	1.7	1.5
10.5	2.7	2.5	1.6	1.4	1.3	1.5	0.9	1.0	3.3	2.9	2.0	1.5
11	3.1	2.3	2.1	1.9	1.3	1.3	0.8	0.8	3.3	2.7	2.0	1.5
11.5	3.2	2.4	1.0	1.7	1.2	1.0	0.6	0.6	2.9	2.4	1.7	1.4
12	3.3	2.1	1.9	1.6	0.9	0.9	0.2	0.5	2.3	2.0	1.5	1.1

(Continued)

APPENDIX S - ATTACHMENT 1

Table 3 (Concluded)

	Velocities at Station 42 980 ft Left of Channel Sta 219+800						Velocities at Station 45 700 ft Right of Channel Sta 197+450				Velocities at Station 54 580 ft Left of Channel Sta 63+950			
	Base Test		Plan A		Plan B		Base Test		Plan A		Base Test		Plan A	
Time	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
0	E 0.0	F 0.1	0.0	F 0.3	E 1.0	E 0.1	F 0.6	F 0.6	F 0.9	F 1.4	F 1.9	F 1.3	F 0.8	F 0.3
0.5	0.6	E 0.3	E 0.5	E 0.1	1.0	0.1	E 0.2	0.1	0.6	0.6	1.7	1.1	0.8	0.2
1	1.9	1.0	1.2	0.7	1.0	0.1	1.0	E 0.4	E 0.1	E 0.4	1.3	0.8	0.6	0.1
1.5	2.6	1.9	1.7	1.3	1.0	0.1	1.9	0.8	1.6	1.0	0.7	0.2	0.4	E 0.1
2	3.0	2.3	2.0	1.7	1.0	0.1	2.5	1.2	1.7	1.1	0.0	E 0.2	0.2	0.3
2.5	3.3	2.5	2.2	2.1	0.8	0.0	3.2	1.5	1.0	1.1	E 0.5	0.5	0.0	0.4
3	3.5	2.7	2.3	2.2	0.5	0.0	3.4	1.9	0.4	1.2	1.0	0.9	E 0.2	0.6
3.5	3.7	2.8	2.5	2.3	0.2	F 0.1	3.5	2.2	1.4	1.3	1.4	1.1	0.6	0.9
4	3.7	2.8	2.6	2.4	0.1	0.1	3.5	2.5	1.9	1.3	1.7	1.3	0.8	1.0
4.5	3.7	2.8	2.6	2.4	0.1	0.1	3.6	2.6	1.9	1.4	1.9	1.4	1.1	1.0
5	3.6	2.6	2.4	2.2	0.1	0.1	3.6	2.6	1.9	1.4	2.2	1.6	1.4	1.0
5.5	3.3	2.4	2.1	2.0	0.0	0.2	3.7	2.5	1.9	1.4	2.2	1.7	1.5	1.0
6	2.6	1.9	1.7	1.5	F 0.1	0.4	3.4	2.2	1.9	1.4	2.2	1.7	1.5	1.0
6.5	1.4	0.8	1.2	0.9	0.2	0.9	2.8	1.9	1.5	1.2	2.2	1.6	1.5	1.0
7	0.0	F 0.1	0.5	0.3	0.4	1.0	1.5	0.9	1.1	0.9	2.2	1.6	1.5	0.8
7.5	F 0.9	1.1	F 0.2	F 0.2	0.7	1.2	0.2	F 0.2	0.4	0.0	2.0	1.5	1.4	0.6
8	2.0	2.0	0.9	0.9	0.6	1.1	F 1.0	1.3	F 0.4	F 1.4	1.7	1.2	1.1	0.5
8.5	3.0	2.5	1.1	1.3	0.2	1.0	1.9	1.7	1.5	1.9	0.9	0.8	0.7	0.5
9	3.7	3.0	1.2	1.6	0.1	0.9	2.4	1.9	1.7	2.0	0.1	0.0	0.3	0.3
9.5	4.0	3.3	1.4	1.8	0.0	0.7	2.7	2.0	1.6	2.2	F 0.4	F 0.6	0.1	0.2
10	4.1	3.5	1.5	2.1	0.0	0.4	2.8	2.0	1.5	2.2	1.0	1.0	0.0	0.0
10.5	4.0	3.5	1.6	2.1	E 0.1	0.1	2.7	1.9	1.4	2.2	1.5	1.2	F 0.2	F 0.2
11	3.5	3.0	1.4	1.9	0.2	0.0	2.5	1.7	1.2	2.2	1.8	1.4	0.5	0.5
11.5	2.4	2.2	0.7	1.4	0.5	E 0.2	2.2	1.6	1.2	2.0	1.9	1.6	0.8	0.8
12	1.2	1.0	0.3	0.7	0.9	0.2	1.7	1.2	1.1	1.5	1.9	1.7	0.8	0.5

APPENDIX S - ATTACHMENT 1

Table 4

Effect of Plan-A Barrier on Salinities

Mean Tide, and Mean Fresh-Water Discharge

1000-ft Channel Station	Base Test Salinities				Plan A Salinities			
	High-Water Slack		Low-Water Slack		High-Water Slack		Low-Water Slack	
	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
350	11,816	12,703	---	11,943	12,383	12,443	9,671	11,782
275	6,751	7,512	2,637	3,207	7,446	8,047	4,217	5,356
250	4,156	5,351	1,719	2,035	4,993	5,720	2,412	4,201
240	---	---	1,260	1,703	4,201	4,803	1,970	3,188
225	2,605	2,985	744	890	3,014	4,249	1,368	1,479
210	1,845	2,067	327	370	1,684	3,346	1,131	1,194
201	---	---	---	---	1,352	2,397	941	1,748
200	1,576	1,703	201	244	1,321	1,970	659	1,178
190	1,070	1,450	96	136	1,321	1,463	355	988
180	598	856	---	54	1,121	1,223	323	880
170	326	434	---	6	463	1,039	178	837
160	166	203	---	0	355	583	116	628
150	71	84	---	---	162	352	30	165
145	---	50	---	---	60	110	25	78
140	---	34	---	---	21	30	15	47
135	---	21	---	---	12	15	8	12
130	---	11	---	---	9	12	5	8
125	---	8	---	---	5	9	4	5
120	---	0	---	---	2	5	0	2
115	---	---	---	---	0	2	---	0
110	---	---	---	---	---	0	---	---

Note: Salinities are in parts per million chlorine.
Channel stations are from Allegheny Ave., Philadelphia.

APPENDIX 8 - ATTACHMENT 2

BRIDGES CROSSING DELAWARE RIVER AND NAVIGABLE TRIBUTARIES
IN TIDAL PORTION ABOVE PROPOSED BARRIER DAM

Miles above Capes or Miles above Mouth	Location	Type	Use	Date Completed	Clearance (in feet) Vertical Mean High Water	Clearance (in feet) Horizontal
	DELAWARE RIVER					
68.9	Pigeon Pt.,Del.-Deepwater Pt., N.J.	Suspension	Highway	1951	175	2,000
96.8	Philadelphia,Pa.-Gloucester, N. J.	Suspension	Highway	1957	150	1,881
100.2	Philadelphia,Pa.-Camden, N. J.	Suspension	Highway	1926	135	1,686
103.2	Camden, N.J. - Petty Island	Trestle Bascule	Railroad	1919	12	80
104.6	Delair, N.J. (1)	Truss Swing	Railroad	1897	48	120
107.2	Tacony, Pa. - Palmyra, N.J.	Truss Bascule	Highway	1929	64	240
117.8	Burlington,N.J.-Bristol, Pa.	Vertical Lift	Highway	1931	62	515
121.2	Florence, N.J.	Through Truss	Highway	1956	135	620
133.4	Trenton, N.J.	Masonry Arch	Railroad	1907	21	58
133.5	Trenton, N.J.-Morrisville,Pa.	Deck Girder	Highway	1952	27	100
133.6	Trenton, N.J.-Bridge St.	Through Truss	Highway	1929	30	203
	TRIBUTARIES OF DELAWARE RIVER (RIGHT BANK)					
	Neshaminy Creek, Pa.					
0.7	Bridgewater-Croydon,Pa.	Fixed	Highway	1939	9.5	100
1.2	Bridgewater-Croydon,Pa.	Fixed	Railroad	1918	12	91
1.3	Bridgewater-Croydon,Pa., U.S. Rt. #13	Fixed	Highway	1928	19	67
	Pennypack Creek, Pa.					
1.0	Tacony Ave., Philadelphia,Pa.	Fixed	Highway	1875	18	116
1.2	Tacony Ave., Philadelphia, Pa.	Fixed	Railroad	1914	8.2	38
2.0	Torresdale Ave., Philadelphia,Pa.	Fixed	Highway	1895	12	77
	Schuylkill River, Pa.					
1.5	Penrose Ave., Philadelphia, Pa.	Fixed	Highway	1951	135	616
3.5	Passyunk Ave., Philadelphia, Pa.	Bascule	Highway	1911	34	200
5.1	Tasker St., Philadelphia, Pa.	Swing	Railroad	-	15	57
5.5	Grays Ferry Ave., Philadelphia,Pa.	Swing	Railroad	1902	22	75
5.6	Grays Ferry Ave., Philadelphia, Pa.	Swing	Highway	1901	22	75
6.2	University Ave., Philadelphia, Pa.	Bascule	Highway	1929	33	100
6.3	Expressway, Philadelphia, Pa.	Fixed	Highway	1959	50	140
6.4	Christian St., Philadelphia, Pa.	Swing	Railroad	1904	26	70
6.7	South St., Philadelphia, Pa.	Fixed	Highway	1922	37	100
7.2	Walnut St., Philadelphia, Pa.	Fixed	Highway	1892	22	113
7.3	Chestnut St., Philadelphia, Pa.	Fixed	Highway	1959	27	159
7.4	Market St., Philadelphia, Pa.	Fixed	Highway	1933	28	164
7.45	Penna. Blvd., Philadelphia, Pa.	Fixed	Highway	1959	24	178
7.5	Arch St., Philadelphia, Pa.	Fixed	Railroad	1930	38	172
7.8	Vine St., Philadelphia, Pa.	Fixed	Highway	1956	20	136
8.1	Spring Garden St., Philadelphia, Pa.	Fixed	Highway	1876	17	280
	Darby Creek, Pa.					
0.34	Essington, Pa.	Bascule	Railroad	1920	4.7	50
0.34	Essington, Pa.	Bascule	Railroad	1924	5.1	50
0.35	Essington, Pa.	Fixed	Highway	1944	22	73
1.3	Prospect Park, Pa.	Fixed	Highway	1932	8	50
4.8	84th St., Philadelphia, Pa.	Fixed	Highway	1915	10	50
	Crum Creek, Pa.					
0.3	Eddystone, Pa.	Fixed	Railroad	1919	3	50
0.35	Eddystone, Pa.	Fixed	Railroad	1926	4.2	50
0.37	Eddystone, Pa.	Fixed	Highway	1944	5.3	45
0.38	Eddystone, Pa.	Fixed	Highway	-	3	75
0.4	Eddystone, Pa.	Fixed	Railroad	1920	1	40
0.9	Eddystone, Pa.	Fixed	Railroad	-	3.1	20
1.0	Eddystone, Pa.	Fixed	Railroad	-	3	12
1.3	Eddystone, Pa.	Fixed	Highway	-	4.1	29
1.4	Woodlyn, Pa.	Fixed	Railroad	-	11	12
1.5	Woodlyn, Pa.	Fixed	Railroad	1915	28	45
	Ridley Creek, Pa.					
0.10	Chester, Pa.	Fixed	Highway	1941	6	40
0.28	Fourth St., Chester, Pa.	Fixed	Highway	1931	16	140
0.30	Chester, Pa.	Fixed	Railroad	-	11	75
0.32	Chester, Pa.	Fixed	Railroad	-	12	75
0.33	Sixth St., Chester, Pa.	Fixed	Trolley	1920	13	73
0.36	Chester, Pa.	Fixed	Railroad	-	20	74
0.66	Ninth St., Chester, Pa.	Fixed	Highway	1930	15	126
0.9	Morton Ave., Chester, Pa.	Fixed	Highway	1917	9.5	50
1.0	Chester, Pa.	Fixed	Railroad	-	12	130

(1) Under modification.

APPENDIX 8 - ATTACHMENT 2 (Cont'd)

BRIDGES CROSSING DELAWARE RIVER AND NAVIGABLE TRIBUTARIES
IN TIDAL PORTION ABOVE PROPOSED BARRIER DAM

Miles Above Mouth	Location	Type	Use	Date Completed	Clearance (in feet) Vertical Mean High Water	Horizontal
	TRIBUTARIES OF DELAWARE RIVER (RIGHT BANK) (CONT'D)					
	Chester River, Pa.					
0.13	Front St., Chester, Pa.	Swing	Railroad	1908	1.5	59
.17	Second St., Chester, Pa.	Fixed	Highway	-	7.9	84
0.23	Third St., Chester, Pa.	Fixed	Highway	-	6	79
0.5	Fifth St., Chester, Pa.	Fixed	Highway	1913	8.3	80
0.6	Sixth St., Chester, Pa.	Fixed	Railroad	1902	26	120
0.7	Seventh St., Chester, Pa.	Fixed	Highway	-	10	184
0.8	Ninth St., Chester, Pa.	Fixed	Highway	1927	11	160
1.0	Chester, Pa.	Fixed	Footbridge	1946	12	90
1.4	Chester, Pa.	Fixed	Railroad	-	19	145
1.6	Kerlin Ave., Chester, Pa.	Fixed	Highway	1922	11	68
	Christina River, Del.					
1.4	Wilmington, Delaware	Swing	Railroad	1888	6.9	90
2.3	Wilmington, Delaware	Bascule	Highway	1915	17.5	145
2.8	Wilmington, Delaware	Bascule	Highway	1957	13.6	175
3.0	Wilmington, Delaware	Bascule	Highway	1928	8.5	175
4.12	Wilmington, Delaware	Swing	Railroad	1888	6.4	63
4.15	Wilmington, Delaware	Swing	Railroad	-	3.2	57
5.4	Wilmington, Delaware	Swing	Railroad	1852	2.4	37
9.5	Newport, Delaware	Bascule	Highway	1929	4.9	49
12.5	Churchman, Delaware	Fixed	Highway	1933	8.0	61
16.0	Christiana, Delaware	Fixed	Highway	1937	6.5	60
	Brandywine River, Del.					
0.1	Seventh St., Wilmington, Delaware	Swing	Highway	1902	11	48
1.1	Eighth St., Wilmington, Delaware	Swing	Railroad	1929	19	48
1.3	Church St., Wilmington, Delaware	Bascule	Highway	1933	12	40
1.7	Sixteenth St., Wilmington, Delaware	Vertical Lift	Highway	1925	10	41
2.0	Market St., Wilmington, Delaware	Fixed	Highway	1929	14	149
	TRIBUTARIES OF DELAWARE RIVER (LEFT BANK)					
	Assiscunk Creek, N. J.					
0.08	Pearl St., Burlington, N. J.	Fixed	Highway	1915	6.3	80
0.22	Burlington, N. J.	Fixed	Railroad	1913	6	25
0.26	Broad St., Burlington, N. J.	Fixed	Highway	1923	6.2	34
0.5	Mitchell St., Burlington, N. J.	Fixed	Highway	1929	8.4	14
0.6	Burlington, N. J.	Fixed	Highway	1936	5	42
	Rancocas River, N. J.					
1.3	Riverside, N. J.	Swing	Highway	1935	4	50
1.6	Delanco, N. J.	Swing	Railroad	1905	5	43
3.3	Bridgeboro, N. J.	Bascule	Highway	1928	8.6	60
7.8	Centerton, N. J.	Swing	Highway	-	6.1	51
8.1	Centerton, N. J., N. J. Turnpike	Fixed	Highway	1951	20	60
11.3	Hainesport, N. J.	Swing	Highway	1933	5	46
11.8	Hainesport, N. J.	Fixed	Railroad	1913	27	48
12.3	Hainesport, N. J.	Fixed	Highway	1933	15	50
13.3	King St., Mount Holly, N. J.	Fixed	Highway	1919	6.3	30
13.4	Water St., Mount Holly, N.J.	Fixed	Railroad	-	13	20
13.7	Washington St., Mount Holly, N.J.	Fixed	Highway	1927	5.5	51
13.8	Bispham St., Mount Holly, N.J.	Fixed	Highway	-	-	-
13.9	Mount Holly, N. J.	Fixed	Railroad	-	-	-
14.1	Mount Holly, N. J.	Fixed	Railroad	-	-	-
14.5	Mount Holly, N. J.	Fixed	Railroad	-	-	-
13.4 (1)	Washington St., Mount Holly, N. J.	Fixed	Highway	-	5	40
13.6 (1)	Mount Holly, N. J.	Fixed	Railroad	-	-	-
14.0 (1)	Pine St., Mount Holly, N. J.	Fixed	Highway	1945	7.5	18
	Pennsauken Creek, N. J.					
1.12	Palmyra, N. J.	Fixed	Railroad	1931	12	50
1.2	Palmyra, N. J.	Fixed	Highway	-	8.5	43
1.5	Palmyra, N. J.	Fixed	Highway	1930	8.5	88
2.5	Five Points	Fixed	Highway	1927	12	64
4.0	Five Points	Fixed	Highway	-	3.8	58
.2	Five Points	Fixed	Highway	1930	4.1	60

(1) Location along cut-off channel.

BRIDGES CROSSING DELAWARE RIVER AND NAVIGABLE TRIBUTARIES
IN TIDAL PORTION ABOVE PROPOSED BARRIER DAM

Miles above Mouth	Location	Type	Use	Date Completed	Clearance (in feet) Vertical Mean High Water	Horizontal
	TRIBUTARIES OF DELAWARE RIVER (LEFT BANK) CONT'D)					
	Cooper River, N. J.					
0.3	State St., Camden, N. J.	Swing	Highway	-	7.7	49
0.9	North River Ave., Camden, N. J.	Swing	Railroad	1930	3.9	35
1.0	Federal St., Camden, N. J.	Bascule	Highway	1908	6.6	60
1.1	Admiral Wilson Blvd., Camden, N.J.	Bascule	Highway	1927	4.7	67
2.2	Baird Ave., Camden, N. J.	Fixed	Highway	-	7.9	39
2.8	Kaighn Ave., Camden, N. J.	Fixed	Highway	1926	5.8	64
	Newton Creek, N. J.					
0.18	Gloucester-Camden, N. J.	Fixed	Railroad	1944	4	20
0.2	Gloucester-Camden, N. J.	Fixed	R.R. & Hwy.	1918	6	20
0.25	Broadway, Gloucester-Camden, N.J.	Bascule	Highway	1916	5.4	50
0.38	Broadway, Gloucester-Camden, N.J.	Fixed	Railroad	-	1.6	10
0.8	Camden, N. J. (north branch)	Fixed	Highway	1956	5.8	12
0.8	Camden, N. J. (north branch)	Fixed	Highway	1956	5.8	12
1.0	Collings Rd., Gloucester (main branch)	Fixed	Highway	1956	5.8	27
1.0	Collings Rd., Gloucester (main branch)	Fixed	Highway	1956	49	245
1.2	Morgan Blvd., Camden (north branch)	Fixed	Highway	1919	8.6	70
1.35	Gloucester, N. J. (main branch)	Fixed	Highway	1956	5.8	12
1.35	Gloucester, N. J. (main branch)	Fixed	Highway	1956	5.8	12
1.5	Nicholson Ave., Gloucester (south branch)	Fixed	Highway	1924	11	45
2.1	Gloucester-Camden, N.J. (south branch)	Fixed	Highway	1956	28	62
	Big Timber Creek, N. J.					
.8	Westville, N. J.	Fixed	Highway	1928	14	60
1.1	Westville, N. J.	Fixed	Railroad	1957	14	60
1.2	Westville, N. J.	Fixed	Highway	1935	14	60
2.5	Bellmawr, N.J.(1)	Fixed	Highway	-	12	60
4.5	N.J. Turnpike	Fixed	Highway	1953	12	60
4.6	North-South Freeway	Fixed	Highway	1956	14	60
6	Runnemede, N. J.	Fixed	Highway	1928	8.8	60
	Woodbury Creek, N. J.					
1.3	Woodbury, N. J.	Swing	Highway	1910	5.5	40
2.0	Woodbury, N. J.	Fixed	Highway	1948	15	55
3.8	Broad St., Woodbury, N. J.	Fixed	Highway	-	4.7	29
	Mantua Creek, N. J.					
1.4	Paulsboro, N. J.	Swing	Railroad	-	1.7	32
1.7	Paulsboro, N. J.	Vertical Lift	Highway	1936	5	75
2.7	Paulsboro, N. J., U.S. Route 130	Fixed	Highway	1953	25	65
5.2	Mount Royal, N. J.	Fixed	Highway	1937	12	68
5.3	Mount Royal, N. J.	Fixed	Railroad	1924	14	42
8.1	N. J. Turnpike	Fixed	Highway	1952	14	60
8.8	Mantua, N. J.	Fixed	Highway	1922	14	67
	Raccoon Creek, N. J.					
1.8	Bridgeport, N. J.	Vertical Lift	Highway	1940	6	65
2.0	Bridgeport, N. J.	Swing	Railroad	1924	7	38
8.3	Swedesboro, N. J.	Swing	Highway	1913	6	50
8.9	Swedesboro, N. J.	Fixed	Railroad	1914	21	33
9.2	Swedesboro, N. J.	Fixed	Highway	1942	8.2	50
	Oldmans Creek, N. J.					
3.1	Nortonville, N. J.	Vertical Lift	Highway	1937	5	75
4.0	Jumbo, N. J.	Swing	Railroad	-	2.1	36
5.1	Pedricktown, N. J.	Swing	Highway	1912	7.8	36
10.7	Auburn, N. J.	Fixed	Highway	1924	7	29

(1) Under construction.

AD-A082 394 ARMY ENGINEER DISTRICT PHILADELPHIA PA F/G 13/2
REPORT ON THE COMPREHENSIVE SURVEY OF THE WATER RESOURCES OF TH--ETC(U)
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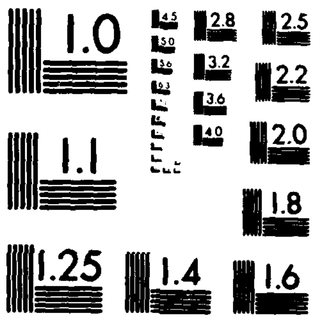

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UNITED STATES
DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
BUREAU OF SPORT FISHERIES AND WILDLIFE
59 TEMPLE PLACE
BOSTON, MASSACHUSETTS

ADDRESS ONLY THE REGIONAL DIRECTOR

NORTHEAST REGION
(REGION 5)
NEW ENGLAND STATES
NEW YORK
PENNSYLVANIA
NEW JERSEY
DELAWARE
WEST VIRGINIA

October 9, 1959

District Engineer
Philadelphia District
U. S. Corps of Engineers
2635 Abbottsford Avenue
Philadelphia, Pennsylvania

Dear Sir:

Enclosed herewith are three copies of our report concerning the types of fish and wildlife studies which would be required if a thorough investigation of a barrier plan for Delaware Bay is to be undertaken.

Thank you for your cooperation in this matter.

Sincerely yours,

E. W. Bailey
Acting Regional Director

Attachments

APPENDIX S
ATTACHMENT 3

UNITED STATES
DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE

October 9, 1959

District Engineer
Philadelphia District
U. S. Corps of Engineers
2635 Abbottsford Avenue
Philadelphia, Pennsylvania

Dear Sir:

In connection with your preliminary report on the feasibility of barrier dam studies in the Delaware River Estuary, a meeting was held October 20, 1958 subsequent to the Public Hearing at Wilmington, Delaware, at which time representatives of this office and other interested Federal and State agencies discussed with Messrs. Wicker and Duck of your staff the scope and nature of the report you are preparing and of the accompanying fish and wildlife report. The latter is contained in the following paragraphs prepared with the cooperation of Dr. Carl N. Shuster, Jr., University of Delaware, Dr. Harold Haskin, Rutgers University, and personnel of the pertinent States and of the Bureau of Commercial Fisheries.

From information furnished to the Delaware River Coordinating Committee by your agency at the meeting held at Split Rock Lodge in May, it is our understanding that preliminary consideration has been given to two types of barrier, each located 3,500 feet downstream from New Castle, Delaware. One type, designated as Plan A, consists of a low dam with a fixed spillway and an unobstructed opening or notch for navigation. The other (Plan B) arrangement provides for navigation through a low dam with a fixed spillway. Tests in the model at Vicksburg have been made on the basis of simulated normal-type conditions. Under Plan A

the range of tide immediately downstream of the barrier would be increased to about 7.7 feet from the range of 5.5 feet, under existing conditions. The high water would be about 1.2 feet higher and lower water about 1-foot lower. At the New Castle gauging station, about 3,500 feet upstream from the barrier location, the range would be 2.3 feet as compared to the 5.5 feet under existing conditions. Similarly, at Philadelphia the range would be 3.5 feet versus the present 5.9 feet. Under existing conditions, the maximum average velocity of tidal flow is between 3 and 3½ feet per second in the vicinity of the proposed barrier site. Under Plan A the comparable velocity would be about 10 feet per second. Tests made for Plan B showed that the range of tide below the barrier would be 9.2 feet, which is about 3.7 feet greater than the present range. Under Plan B high water would be about 2.2 feet higher and low water about 1½ feet lower than stages under existing conditions at the barrier location. With respect to salinity tests, no results are presently available.

The basic purpose of such a structure would be to provide a source of fresh water in a particular area of the basin. In considering this means of achieving such a worthwhile purpose, however, the effect upon other activities centered around and dependent upon the Delaware River Estuary must be taken into account.

The Delaware Bay is known to support one of the most productive commercial inshore fisheries along the Atlantic coast. The value of all fisheries landings directly from the Delaware Bay varies from $4,000,000 to nearly $6,000,000 annually. These are dock-side values. The Bay directly produces from 12,000,000 to 15,000,000 pounds of food stuffs annually. The term "directly" is employed because it is a virtual certainty—and this is all-important—that the Bay plays a major role in maintaining the prosperity of certain oceanic fish stocks. The extent of this contribution, in terms of total volume or in more quantitative terms, is largely unknown. This aspect, however, of the Bay's significance is rather well documented in the case of certain species such as shad, striped bass, and menhaden. It is known, for example, that between 35 and 51 percent of the total annual catch of Atlantic menhaden comes from waters in the immediate vicinity of Delaware Bay.

Insofar as the commercial fishery products secured directly from the Bay are concerned, the oyster contributes

over 90 percent of the total value. Landings of so-called finfish species from the Bay, in recent years, have had an average value of only about $170,000 per year; but it is important to emphasize again that the Bay is undoubtedly a vital element in maintaining offshore productivity. The total value of New Jersey and Delaware landings, including offshore fisheries, in a recent year (1954) was over $22,000,000.

It is obvious that the construction of a barrier in the general New Castle area will have an impact on the environment upstream and downstream from the project. Upstream from the area, reservoir conditions would obtain and water levels would probably be relatively well stabilized as compared to the present. There also will be problems in fish passage. Obviously, if anadromous and catadromous fishes such as alewives, shad, striped bass, and eels are to be maintained in the basin, suitable fish passages would have to be provided. The exclusion of these endemic fish populations which presently use this reach of the river would preclude completion of certain stages in their life cycles and thus result in an irreplaceable loss of these populations to the stock. There is also concern regarding the possible effects of pollution in the post-construction period within the reservoir. Water quality might prove to be poorer than at present, with sludge deposits being formed with high oxygen demands. On the other hand, the existence of the barrier could result in improvements in the habitat for fresh water fishes.

Of course, the more important segment of the fishery is found in the Bay below the probable location of the barrier or in adjoining offshore areas. The existence of the barrier could be expected to bring about changes in flow regimens, sedimentation, salinity patterns, temperatures, currents, volume or type of nutrients, tidal actions, etc. Changes in these features could be expected to alter the distribution and abundance of the plant and animal populations which now occur in the Bay because of its present unique characteristics.

Waterfowl consisting of ducks, geese, brant, and certain associated species, such as rails, and coots together with fur animals, of which the muskrat is most important, comprise the major wildlife resources of the Delaware River Estuary. The tidal marsh in the estuarine area supplies habitat to both groups. While waterfowl also use the open waters and the tidal mud flats, it would be difficult to overestimate the importance of the Delaware River estuarine habitat to both groups.

From Trenton, New Jersey to the entrance of the Delaware Bay, there stretches one vast complex of interrelated waterfowl habitats, much of which consists of fresh tidal marsh—the most productive of the coastal habitat types. Utilization by waterfowl for migration, wintering, and breeding is measured in the millions of duck days, a standard measure of such use. Hunting pressure is high and two national wildlife refuges, as well as thousands of acres of State waterfowl management areas, are located in the Delaware River Estuary. Quantitatively, the largest share of this habitat is downstream from the site of the proposed barrier, although upstream there are many choice areas also. Wetlands destruction through filling, spoil disposal, and other means has been particularly severe upstream from the proposed barrier site.

The Delaware River estuarine marshes are the most important single habitat block for fur production in the northeastern and middle Atlantic States. This production depends very largely on muskrat. Muskrat trapping partakes something of the nature of an industrial enterprise with large areas owned or leased solely for this purpose. Current low prices for raw furs have had a depressing effect, but the muskrat still remains the backbone on the fur business and an upturn in demand is likely.

Upstream from the proposed barrier the present gradation from salt to fresh water in the estuary will become a fresh water lake with relatively limited fluctuations. Changes in water chemistry, pollution concentration, and sedimentation patterns are also likely. Certain indirect changes such as wetlands encroachment by industry and agriculture attracted by improved water supplies and flood protection may result. These and other factors, whose exact nature and potential magnitude are not known at present, warrant serious analysis in terms of their effects on wildlife habitat. This is particularly true of the changes in water levels which may be anticipated. At present, the estuarine wetlands habitat ranges from areas inundated infrequently (by only the highest tides) to areas which even at low tide are still too deep for other than submergent aquatic vegetation. Stabilization at a high tide level will improve the former and eliminate an unknown amount of the latter. The intermediate areas now alternately exposed and flooded by normal tidal action would be adversely affected by stabilization. Since the estuarine profile from dry land to the deepest part of the channel does not change

at a uniform rate, the quantitative results, in terms of total wetlands acreages, and acreages of various wetlands types at the proposed stabilized water levels would have to be investigated. If stabilization of water levels somewhere near high tide level comes about, there may be a reduction in the need for navigational dredging with its consequent problems of spoil disposal, which have been so detrimental to wetlands habitat in the past.

Downstream from the barrier site changes in salinity and in the magnitude of tidal fluctuations will be more important from the standpoint of impact on wildlife resources. While firm information on these changes is lacking, indications point toward higher water levels, greater salt water intrusion, and possibly a greater tidal range. Since low or wet salt marsh is preferable to high or dry salt marsh, from the wildlife viewpoint, the first of these changes might be beneficial. The other two would, generally speaking, be unfavorable. The best natural waterfowl producing areas lie along the Bay tributaries extending upward from the limited salt water intrusion to the head of tide. Further salt water intrusion would reduce and impair these productive areas. Careful analysis would be necessary to balance one set of considerations against the other. Also more subtle changes in water chemistry and nutrients, sedimentation patterns, currents and hydrology, and pollution patterns could affect the quality of wildlife habitat.

In short, construction of the proposed barrier could trigger a complex and interrelated set of reactions, some of which appear to be favorable to estuarine wildlife habitat and some unfavorable. One thing is obvious, there is not one simple clear-cut answer to the question of what effects the proposed barrier might have. In order to be able to analyze project operation as it is predicted by the Corps of Engineers from model studies or other means, it will be necessary to know far more than is known at present about the relationship between existing tides, currents, salinity, sediment, nutrients, and other factors and the flora and fauna of the estuary.

In considering the studies required, attention is directed first to the oyster, because of its recognized importance among fishery products originating within Delaware Bay itself. If it is to continue as such an important item, conditions favorable to reproduction, "setting", growth, and freedom from enemies and disease must be maintained. Delaware Bay oysters do not reach a spawning peak until water temperature is about 77° F. The time will vary

from year to year. After spawning takes place, within 5 to 10 hours, the small free-swimming oyster larvae develop. The young remain free-swimming for about 2 weeks. During this time they are vulnerable to tides and currents and numerous enemies. When larval development has been completed, the young oyster requires some hard clean object in the water where it can attach itself and thereafter remain fixed for the rest of its life. At the time of setting, if the young find no suitable place of attachment, they die. In Delaware Bay the period from June through September is most critical as to oyster setting. Oysters set in great numbers in Delaware Bay, using beds along both the Delaware and New Jersey shores, but being more abundant toward the latter. What makes the Bay particularly favorable for setting is not fully understood.

Temperatures affect the time of oyster spawning. Temperatures and salinities and the abundance of nutrients brought to the oyster beds by the circulating waters are major factors in growth. The optimum temperature for growth of oyster spat appears to be about 77° F. Feeding rate apparently reaches a maximum between 82° and 86° F. It must be determined how the conditions existing in Delaware Bay are related to optimum growing conditions before a determination can be made as to whether changes brought about by a barrier would be beneficial or detrimental. Oyster production above the barrier would probably be eliminated.

Certainly an intimate knowledge (1) of existing tidal effects, flushing rates and other current movements in relation to oyster beds, (2) of the volume, type, and source of nutrients available, (3) of existing patterns of salinity, sedimentation, larval movements, and oyster growth in relation to conditions as they exist in Delaware Bay must be obtained as a prerequisite to an accurate analysis of barrier effects. The role of currents in the Bay is of special importance to the oyster resource . The part of the Bay most important to the oyster industry is the Natural Seed Bed area, between Fake Egg Island Point (off Fortescue) and Mad House Creek. This is important because it is the area in which setting of oysters has occurred consistently over the years to provide seed for the operation of the entire industry. There is little doubt that the setting patterns are established by current patterns. The proposed barrier would undoubtedly change drastically the tidal currents in this upper Bay area. This provides a clear-cut reason for detailed current studies in relation to oyster-setting in the area.

To obtain reliable knowledge will require collection of data and analysis over a period of five years. The services of a hydrographer and an assistant will be required to study current and tide data. About 15 monitoring stations, equipped with devices to give a continuous record, will be needed. It is hoped that this equipment, together with the necessary operation and servicing work, can be done by the Coast and Geodetic Survey. Otherwise it will be necessary to secure a suitable boat and equipment and provide for captain, crew, and the operation and maintenance charges. It is estimated that cost for hydrographic data collection, including boat, equipment, salaries, operation, and maintenance would amount to $300,000 for the five-year period, assuming active use of boat about two-thirds of each year.

Collection of data on larval oyster movements and nutrients could best be done by use of a smaller boat, 38-40 feet long, with twin diesels for speed, since there is need to get from one place to another quickly. It should have cabin space for four men and a small laboratory for nutrient studies. Equipment should include radar, continuous plankton recorder, fathometers, winch, and, if possible, a device for sorting larvae almost immediately. Such a device will need to be designed specially. The crew would include the captain, a biologist, at least one chemist, and one or more laboratory assistants. Cost of this study, including boat, equipment, salaries, operation, and maintenance would amount to $300,000 for five years. Other data required in connection with the effect of barrier construction on the oyster fishery of Delaware Bay could be obtained largely by analysis of information resulting from studies by the Corps of Engineers as to flow regimens, the contribution of fresh water to the area downstream from the Bay, predicted effects on currents and tides, and resultant modification of mixing patterns. It is probable, also, that the data obtained from the hydrologic and biological studies mentioned above, together with that provided by Corps of Engineers studies, will help serve as a basis for analysis of the effects of the barrier upon other fisheries resources, including finfisheries, dependent upon the estuary. However, an additional $30,000 annually or $150,000 for a five-year period, should be included in the cost of studies required.

Furthermore, to provide predictive data, analogous to those furnished by physical model studies, it is requested that funds be provided for a biological model study. This essentially would consist of a detailed study of the biological and hydrographic characteristics of a relatively small tidal

estuary located in the near-vicinity of the Delaware estuary. Measurements of the ecological features of the model estuary will be conducted over a period of two complete biological cycles (two calendar years). At the end of the two-year period, a barrier, of the type proposed for the Delaware estuary, will be constructed and continuing measurements of the ecological features conducted for an additional three-year period for the purpose of determining changes resulting from the barrier. The importance of such a study in providing quantitative data upon which to evaluate the effects of barrier construction on the complex biological and hydrographic relations and interrelations within an estuary cannot be overemphasized. Cost of this study, including equipment, laboratory facilities, and salaries would amount to $50,000 annually or $250,000 for the five-year period.

To an important degree, the data from the above studies will help in analyzing the effects upon wildlife resources, particularly waterfowl. In addition, a study of the ecology of important wildlife species in order to properly understand the significance of existing and predicted future conditions will require the efforts of biologists over a period of five years, at an estimated cost of $60,000.

Although certain phases of the total program possibly could be completed with sufficient accuracy in a three-year period, it is evident that five years will be required to yield satisfactory results. Therefore, estimates have been made on the basis of a five-year program.

In conclusion, therefore, if an investigation of survey scope is to be made in order to evaluate and develop a plan for a Delaware Bay Barrier, provision should be made for biological and related hydrographic studies, to be carried out by the Fish and Wildlife Service in cooperation with State and other agencies over a period of five years, at an estimated cost of $1,060,000.

Sincerely yours,

E W Bailey

E. W. Bailey
Acting Regional Director
Bureau of Sport Fisheries and Wildlife

Russell T. Norris

Russell T. Norris
Acting Regional Director
Bureau of Commercial Fisheries

DEPARTMENT OF
HEALTH, EDUCATION, AND WELFARE
REGIONAL OFFICE

PUBLIC HEALTH SERVICE

REGION II
42 BROADWAY
NEW YORK 4, N.Y.

November 18, 1959

Refer to: 24:SE

District Engineer
U. S. Army Engineer District, Philadelphia
Corps of Engineers 2635 Abbottsford Ave
Philadelphia 29, Pa.
Attn: NAPDV

Dear Sir:

Reference is made to your letters of December 2, 1958 and June 11, 1959 relative to the feasibility of constructing a locked barrier at mean high water in the Delaware Estuary. As Mr. Klashman stated at the public hearing of October 20, 1958, a detailed study of the stream would be necessary before we could make a complete determination of the effects of such a barrier on water quality.

In your letter of December 2, 1958 you requested an expert opinion based upon comparable experiences elsewhere. Unfortunately the opinion you request must be based on rationalization since the construction of such a salt water barrier is uncommon.

The barrier will change the basic hydraulics of the stream. When water in a free flowing or a tidal stream is impounded, changes in the physical, biological, bacteriological and sanitary-chemical quality of the water are produced. The degree and the direction of the change depend on the specific situation. The estuary which is presently subjected to a twice daily flushing as a result of the tidal movement would become in essence a fresh water lake.

Physical

Tidal currents which normally carry in suspension silt, organic material and sewage particles will no longer be available

to disperse these materials. This could create higher concentrations of pollutants in some areas. The dilution and cleansing effect of the tidal currents would no longer be available. The temperature of the water upstream of the barrier can be expected to increase significantly above the presently observed maximums. There will also be concommitant effects on biological and chemical quality due to the temperature change.

Biological

The change in habitat characteristics (eg. brackish to fresh, warmer temperatures) would change the biological species that would prevail. Evaluation of this would be made by the Fish and Wildlife Service.

Bacteriological

Bacteriological counts would probably increase because of the decrease in the available dilution water. Sea water contains bactericidal properties not completely evaluated at this date. These properties of seawater will not be present in the proposed fresh water lake.

Sanitary-Chemical

Presently some 770,000 pounds of Biochemical Oxygen Demand are discharged daily to the tidal stream upstream of the proposed barrier location. The rate of reaeration in the present stream would undoubtedly be decreased. This would cause oxygen deficits to exist for larger periods of time then those presently experienced. The determination of the extent of the oxygen depressed areas and the actual oxygen deficit will require detailed study. With lower velocities in the barrier pool, sedimentation of silt and organic sewage and non-sewage particles would create deposits and possibly sludge banks. These deposits would in turn create a higher benthal demand for oxygen from the stream than that now experienced.

Toxic chemicals, oils and tastes producing compounds would be present to a greater degree than prior to the barrier because of the lesser quantities of dilution water that would be available.

In addition, with the change in the water level, problems in the hydraulics of some of the older sewer systems and treatment plants may require costly remedial alterations.

A more complete evaluation of the proposed barrier would require a comprehensive study and surveyof the affected areas to determine actual water qualities and the costs and benefits involved.

Sincerely yours,

Sylvan C. Martin
Sanitary Engineer Director, PHS
Regional Engineer